TCMS

ELEMENTS OF
ANIMAL NUTRITION

OTHER BOOKS OF INTEREST

Foods: their composition and analysis	A.W. Blyth and H. E. Cox
Elementary agricultural chemistry	H. Ingle
Management of pure yeast	A. Jorgensen
Micro-organisms and fermentation .	A. Jorgensen and A. Hansen
Water analysis	H. B. Stocks
Practical sanitation . . .	G. Reid and J. J. Buchan

ELEMENTS OF ANIMAL NUTRITION

W. M. ASHTON
B.Sc., Ph.D., A.R.I.C.

Senior Lecturer in Agricultural Chemistry
University College of Wales, Aberystwyth

CHARLES GRIFFIN & COMPANY LIMITED
42 DRURY LANE, LONDON, WC2

Published in 1950

PRINTED IN GREAT BRITAIN BY LESLIE G. LUKER, LONDON, S.W.8

PREFACE

THE AIM of this book is to give a concise account of the basic principles underlying the feeding of farm animals. Despite the fact that there are many excellent books on animal nutrition, it is difficult at the present time to refer students to a volume of moderate size dealing with the chemistry and digestion of food constituents, the foods commonly met with in farm practice, feeding standards and their application in constructing rations for farm animals.

Considerable emphasis is laid on the derivation, meaning and calculation of starch equivalents, with the object of giving a clear understanding of the exact meaning of the term, and enabling students to calculate the starch equivalent of a food from the requisite data, an exercise which they are prone to neglect. An attempt is made to show how to apply the starch equivalent system intelligently, with due appreciation of its advantages and limitations, and to indicate the extent to which it can be used in feeding the different classes of farm animals. The American and Scandinavian systems of evaluating foodstuffs are also described, and a good deal of attention is given to the importance of minerals and vitamins in addition to protein and energy-giving substances.

The reader will realise that many of the foods described and used to illustrate the way in which rations are constructed are at present unobtainable or in short supply. Consequently, home grown foods are of greater importance than ever, and as much space as possible in a volume of this size is devoted to them.

While intended primarily for undergraduate students in Agricultural Chemistry, it is hoped that agricultural students generally, including those taking the National Diplomas in Agriculture and Dairying, will find the book useful. A previous knowledge of chemistry is assumed, such as that acquired in courses of Higher Certificate or Intermediate standard, or courses leading to second year diploma work. The selected bibliography includes some elementary and more advanced books on organic chemistry, and students will find it useful to consult such works in order to supplement their knowledge of the fundamental chemistry underlying the subject matter of Chapters 1–3, and Chapter 5. While a good deal of emphasis is laid on the chemical aspects of the subject, it is hoped that students who are not specialising in chemistry will be able to follow the main theme of the book. This volume is, of course, an introduction to the very wide subject of animal nutrition, and the

reader is urged to consult the original papers quoted, as well as the books and bulletins suggested for further reading.

I would like to express my indebtedness to the authors and publishers of many of these works, and I have made acknowledgements in the text wherever possible. I am also indebted to the Controller, H.M. Stationery Office for permission to quote certain data in the text and in the Appendix Tables.

My warmest thanks are due to Emeritus Professor T. W. Fagan, M.A., F.R.I.C., Mr R. O. Davies, M.Sc., F.R.I.C., Mr Richard Phillips, M.Sc., A.R.I.C., and Professor W. Ellison, Ph.D., for their valuable help and criticism. I would also like to express my sincere thanks to other colleagues and friends who have read part of the manuscript, and helped in any way, and to Messrs Charles Griffin and Co. Ltd, who have, at all times, been most co-operative and helpful.

ABERYSTWYTH W. M. ASHTON

CONTENTS

INTRODUCTION

All living organisms need supplies of food to provide them with the materials necessary for healthy life and growth. While plants grow in one particular situation and do not differ in temperature from the surrounding atmosphere, animals are usually more or less active and their bodies are warmer than their surroundings. Animals, therefore, need food to supply energy for locomotion and the maintenance of body temperature, and for many other purposes, namely, the growth of the skeleton and its covering of muscle and flesh, the growth of tissues such as hair, wool, hoof, horn and feathers, the production of fat, milk and eggs, and reproduction.

To understand how a food meets these various requirements, it is necessary to study the nature and properties of the individual substances which constitute a food. Before attempting a detailed description of these constituents, it will be of considerable advantage to obtain a general idea of their nature, and so to build up a scheme to be kept in mind when studying almost any feeding stuff. It should be realised at the outset that the vast majority of materials used in feeding farm animals are of plant origin, whether produced on the farm or imported, so that we are mainly concerned with a study of plant constituents and their use in animal nutrition. It will be well here to refer to the fundamental difference which exists between plants and animals in their ability to utilise various substances as sources of food. Whereas plants are able to use carbon dioxide, water and simple mineral salts to build up complex organic compounds, the animal, lacking this ability, is ultimately wholly dependent upon the plant for its supply of food.

Most foods are mixtures of a number of compounds, some fairly simple in nature, others very complex. The simplest is water which is present in all animal foods, and varies in extent from about 10 to 20 per cent in comparatively dry foods like cereals and roughages, to 70-90 per cent or more in succulent foods, comprising roots, grass, silage, kale, cabbage, rape and similar green crops. Water is so easily obtainable in temperate climates that its importance is easily overlooked, and it is, of course, absolutely essential for plant and animal metabolism. To build up one part of dry matter, a plant transpires up to 1,000 parts of water, and neither plants nor animals can utilise their food until it has been rendered completely soluble. About two-thirds of the weight of the animal body consists of water, and among animal products rich in water, milk contains on an average 87·5 per cent and eggs 66 per cent. The importance

of water for the formation of blood, the digestive juices and all body secretions is obvious, and its indispensability may be emphasised further by reference to the statement, made by Rubner, " that a starving animal may lose nearly all its glycogen and fat, half of its body protein and about 40 per cent of its body weight, and still live, whereas the loss of 10 per cent of its water causes serious disturbances, and the loss of twice that amount causes death."

One may regard a food as a mixture of water and dry matter, and the former is expelled by heating at 100°C until a constant weight is obtained. By heating more strongly, for instance, at dull red heat, the dry matter remaining may be further resolved into two fractions, the organic matter which burns away completely, and the so-called mineral matter or ash remaining as a greyish-white residue. The latter contains the sodium, potassium, calcium, iron, phosphorus, sulphur, chlorine and other " mineral elements " present in the food. The organic portion may be further subdivided into nitrogenous and non-nitrogenous fractions. In the nitrogenous fraction are the proteins, and this very important group of compounds contains carbon, hydrogen, oxygen and nitrogen; some proteins contain sulphur and/or phosphorus in addition. The nitrogenous fraction also includes simpler compounds known collectively as amides. The non-nitrogenous constituents contain carbon, hydrogen and oxygen only, and comprise the fats and oils and carbohydrates, the latter being made up of starches and sugars or soluble carbohydrates, and crude cellulose or crude fibre.

This outline of the general nature of a food may be summarised as follows—

FOOD

- Water
- Dry matter
  - Organic matter
    - Nitrogenous substances
      - True protein
      - Amides
    - Non-nitrogenous substances
      - Carbohydrates
        - Soluble carbohydrates
        - Crude fibre
      - Fats and oils
  - Inorganic or mineral matter or ash

Different foods vary enormously in composition. As stated above, succulent foods are rich in water, while cereal grains are comparatively dry foods. Similarly, foods may be characterised by their richness or poverty in carbohydrates, fats and proteins, and further reference is made to this in Chapter 8 where variation in composition is used as a basis of classification.

CHAPTER 1

THE FATS AND OILS

FATS and oils are widely distributed in the animal and vegetable kingdoms. Lard, beef and mutton tallow, butter and whale oil are important animal fats, while oils occur to a greater or less extent in all plant tissues. Vegetable oils are obtained from seeds, kernels, nuts and beans, such as linseed, cotton-seed, palm kernels, earth-nuts and soya-beans, which contain approximately 37, 24, 49, 45 and 18 per cent of oil respectively. Extraction is achieved by submitting the oil-bearing tissues to hydraulic pressure, a method employed when the oil is required for the manufacture of margarine or other foods. The residues form a valuable source of oil-cakes and meals for animal feeding but, if necessary, further extraction is accomplished by using such solvents as benzine and petrol (see Chapter 11).

There is no fundamental difference between a fat and an oil, and oils which are fluid at ordinary temperatures solidify when cooled sufficiently, whereas a fat becomes oily when heated. Arachis or peanut oil, for example, solidifies to fat in winter, and fats which appear to us as solids may be liquid in the living organism. Fats and oils are compounds of glycerol, which is a trihydric alcohol, and fatty acids. The simplest fatty acid found in natural fats is butyric acid, which may be regarded as combining with glycerol to form a simple ester, tributyrin—

$$\begin{array}{l} CH_2{\cdot}OH \\ | \\ CH{\cdot}OH \\ | \\ CH_2{\cdot}OH \end{array} + 3C_3H_7COOH \quad = \quad \begin{array}{l} CH_2{\cdot}OOC{\cdot}C_3H_7 \\ | \\ CH{\cdot}OOC{\cdot}C_3H_7 \\ | \\ CH_2{\cdot}OOC{\cdot}C_3H_7 \end{array} + 3H_2O$$

Glycerol   Butyric acid   Glycerol tributyrate or Tributyrin

One might similarly represent tripalmitin and tristearin, but it is very unlikely that a glyceryl residue is attached to one and the same fatty acid, for natural fats contain "mixed glycerides" such as palmito-oleo-stearin—

$$\begin{array}{l} CH_2{\cdot}OOC{\cdot}C_{15}H_{31} \\ | \\ CH{\cdot}OOC{\cdot}C_{17}H_{33} \\ | \\ CH_2{\cdot}OOC{\cdot}C_{17}H_{35} \end{array}$$

The following fatty acids are of common occurrence in nature—

Saturated fatty acids : General formula $C_nH_{2n+1}COOH$.

Acid	*Formula*	*Acid*	*Formula*
Formic	$H \cdot COOH$	Lauric	$C_{11}H_{23} \cdot COOH$
Acetic	$CH_3 \cdot COOH$	Myristic	$C_{13}H_{27} \cdot COOH$
Propionic... ...	$C_2H_5 \cdot COOH$	Palmitic	$C_{15}H_{31} \cdot COOH$
Butyric	$C_3H_7 \cdot COOH$	Stearic	$C_{17}H_{35} \cdot COOH$
Caproic	$C_5H_{11} \cdot COOH$	Arachidic ...	$C_{19}H_{39} \cdot COOH$
Caprylic	$C_7H_{15} \cdot COOH$	Behenic	$C_{21}H_{43} \cdot COOH$
Capric	$C_9H_{19} \cdot COOH$	Lignoceric ...	$C_{23}H_{47} \cdot COOH$

Unsaturated fatty acids : $C_nH_{2n-1}COOH$ to $C_nH_{2n-7}COOH$

These may contain one or more double bonds in the molecule. Thus oleic acid $C_{17}H_{33} \cdot COOH$ contains one double bond, and linoleic acid $C_{17}H_{31} \cdot COOH$, linolenic acid $C_{17}H_{29} \cdot COOH$ and arachidonic acid $C_{19}H_{31} \cdot COOH$, contain 2, 3 and 4 double bonds respectively.

The lower members, formic, acetic and propionic acids are not present in fats, but occur in perspiration, urine and faeces, and may be present in fermented foods such as silage. The higher members, on the other hand, are widely distributed in natural fats. Palmitic, stearic and oleic acids are the chief acids present in beef and mutton tallow, comparatively hard fats, and palm oil consists mainly of esters rich in palmitic and oleic acids. The consistency of fats depends on the nature of the fatty acids present, as unsaturated acids produce an oily consistency. Comparatively soft fats such as lard and butter contain a higher proportion of unsaturated acids, and vegetable oils such as cotton-seed and olive oils consist mainly of esters rich in oleic and linoleic acids, while linseed oil contains, in addition, a high proportion of linolenic acid. Butter fat contains all the above saturated acids between $n=3$ and $n=19$ as well as oleic and linoleic acids, and assumes a more oily consistency when the amounts of the latter are increased after the cattle go out to pasture in the spring, or receive comparatively large quantities of linseed cake in their winter rations.

It is interesting to note that all naturally occurring higher fatty acids except isovaleric acid, a branched chain acid C_4H_9COOH, contain an even number of carbon atoms, a fact which may be explained by assuming that their metabolism involves units containing two or a simple multiple of two carbon atoms.

Properties and uses of fats and oils

Fats and oils are insoluble in water with which they form emulsions, but dissolve readily in ether, petroleum spirit, chloroform, carbon

tetrachloride, carbon disulphide and many other organic solvents. On heating with concentrated aqueous and alcoholic sodium or potassium hydroxides they are hydrolysed to give glycerol and soaps—

$$\begin{array}{lcccccc} CH_2{\cdot}OOC{\cdot}C_{15}H_{31} & & & & CH_2{\cdot}OH & & \\ | & & & & | & & \\ CH{\cdot}OOC{\cdot}C_{15}H_{31} & + & 3NaOH & = & CH{\cdot}OH & + & 3C_{15}H_{31}{\cdot}COONa \\ | & & & & | & & \\ CH_2{\cdot}OOC{\cdot}C_{15}H_{31} & & & & CH_2{\cdot}OH & & \\ \text{Glyceryl palmitate} & & & & \text{Glycerol} & & \text{Sodium palmitate} \\ \text{(Palmitin)} & & & & & & \text{(A soap)} \end{array}$$

This process, known as saponification, is important industrially in the manufacture of soap.

Fats are important articles of food, and blends of animal and vegetable oils are extensively used in making margarine and lard substitutes by a process of catalytic hydrogenation. Hydrogen under pressure is passed into the heated oils in the presence of finely divided nickel spread over the surface of charcoal or kieselguhr. Under these conditions hydrogen adds on to the double bonds of the unsaturated acids, and the process is stopped when the mixture attains the desired consistency, for complete saturation would yield a very hard fat. The principle involved may be illustrated by reference to the hydrogenation of oleic acid—

$$C_{17}H_{33}COOH + H_2 \rightarrow C_{17}H_{35}COOH, \textit{ or}$$

$$\underset{\text{Oleic acid}}{CH_3{\cdot}(CH_2)_7{\cdot}CH{=}CH{\cdot}(CH_2)_7{\cdot}COOH} + H_2 \rightarrow \underset{\text{Stearic acid}}{CH_3{\cdot}(CH_2)_7{\cdot}CH_2{-}CH_2{\cdot}(CH_2)_7{\cdot}COOH}$$

Finally, vitamin concentrates are added to give the margarine a vitamin potency equal to that of good quality butter.

Unsaturated fatty acids may be saturated by the addition of iodine, and this is used to measure the degree of unsaturation of an oil, the "iodine number" being the number of grams of iodine absorbed by 100 grams of the oil.

There are several other properties which are used to characterise a fat or oil, such as melting point and certain constants. Fats do not melt nor oils solidify at well-defined temperatures because they are a mixture of various glycerides. Nevertheless, the "melting point" is useful in helping to identify them. The variation in amounts of volatile fatty acids and acids of low molecular weight affords a useful basis for further methods. Thus the Reichert-Meissl-Wollny number is the number of ml of 0·1N-NaOH required to neutralise the soluble volatile fatty acids in 5 grams of fat. Because it contains a much higher proportion of volatile fatty acids than other fats, butter has a high Reichert-Meissl-Wollny

number, which is one of its most important properties for purposes of identification. The Polenske number too is useful in this respect ; it is the number of ml of 0·1N-NaOH required to neutralise the insoluble volatile fatty acids (dissolved for this purpose in alcohol) in 5 grams of fat. The Koettstorfer or Saponification number is the number of mg of KOH required to saponify 1 g of fat. The amount of KOH required is greater the higher the content of fatty acids of low molecular weight for, as will be seen from the following equation, 302 grams of tributyrin and 890 grams of tristearin are hydrolysed by the same weight (168 grams) of KOH.

$$\begin{array}{l} CH_2{\cdot}OOC{\cdot}C_3H_7 \\ | \\ CH{\cdot}OOC{\cdot}C_3H_7 \\ | \\ CH_2{\cdot}OOC{\cdot}C_3H_7 \end{array} + 3KOH = \begin{array}{l} CH_2{\cdot}OH \\ | \\ CH{\cdot}OH \\ | \\ CH_2{\cdot}OH \end{array} + 3C_3H_7{\cdot}COOK$$

Glyceryl tributyrin M.W. 302 — Glycerol — Potassium butyrate

$$\begin{array}{l} CH_2{\cdot}OOC{\cdot}C_{17}H_{35} \\ | \\ CH{\cdot}OOC{\cdot}C_{17}H_{35} \\ | \\ CH_2{\cdot}OOC{\cdot}C_{17}H_{35} \end{array} + 3KOH = \begin{array}{l} CH_2{\cdot}OH \\ | \\ CH{\cdot}OH \\ | \\ CH_2{\cdot}OH \end{array} + 3C_{17}H_{35}{\cdot}COOK$$

Glyceryl tristearate M.W. 890 — Glycerol — Potassium stearate

Table 1 gives the values of some of the most important constants in the case of some common fats and oils, taken mainly from data given by such authorities as Hilditch and Lewkowitsch—

TABLE 1

Fat or oil	Melting point °C	Iodine number	Reichert-Wollny No.	Polenske No.	Saponification No.
Butter fat	28–33	26–45	24–32	2–3	216–235
Lard	36–41	46–66	0·7	—	193–200
Whale oil	—	121–136	0·7–2·0	—	188
Mutton tallow	44–45	31–47	—	—	192–198
Beef tallow	45–50	32–47	0·25	—	190–200
Linseed oil	—16 – —20	170–185	1·0	—	189–196
Cotton-seed oil	—	103–111	0·5–1·0	0·5	191–196
Coconut oil	21–24	8–10	7–8	15–17	250–260
Palm kernel oil	23–28	15–18	5–7	10–12	243–250
Olive oil	—	79–88	0·6	—	185–196

In addition to the difference in the values of these constants which exists between one fat and another, it is also apparent that different samples of any one oil may exhibit considerable variation in properties. In spite

of this, however, the constants afford a useful means of identifying oils and detecting certain types of adulteration, in particular, the adulteration of butter with margarine containing vegetable oils or of margarine with butter.

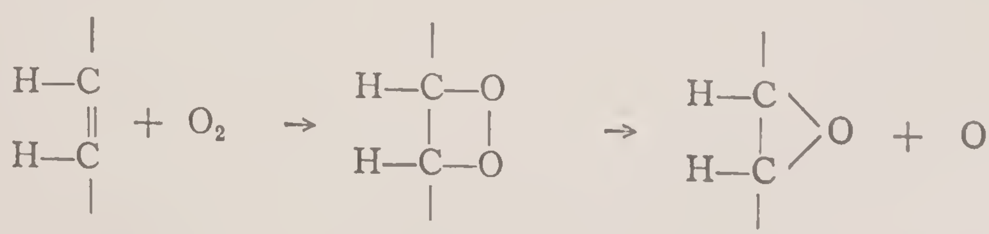
In this connection reference should be made to one important difference which exists between fats of animal and vegetable origin. The unsaponifiable residue of fats contains certain members of a series of higher alcohols or sterols, the most important being cholesterol $C_{27}H_{45}OH$ and phytosterol (a mixture of sterols). Cholesterol appears to be confined almost exclusively to animal fats, and phytosterol to vegetable fats, a fact which enables one to determine with a high degree of certainty whether butter fat has been adulterated with a vegetable oil. For this purpose the fat is saponified, the sterols are isolated from the unsaponifiable residues as the corresponding digitonin sterides and subsequently converted into acetates. After repeated recrystallisation from ethyl alcohol the melting points of the acetates are determined, that of cholesteryl acetate being 113°-115°C and phytosteryl acetate about 124°C.

Rancidity of fats and oils

Fats and oils are hydrolysed by the enzyme lipase with the production of free fatty acids and development of rancidity. In the case of butter, slight hydrolysis produces marked rancidity, because of the very pronounced odour of the butyric acid produced. Development of hydrolytic rancidity may be controlled by inactivating the enzyme by pasteurising the cream. Rancidity is also produced by certain moulds which grow upon butter and break down the lower fatty acids to ketones such as $C_5H_{11}CO{\cdot}CH_3$ and $C_9H_{19}CO{\cdot}CH_3$. These substances cause the development of taints known as " ketonic " rancidity.

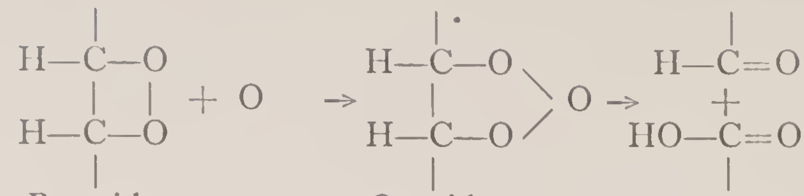
A further type of rancidity is due to the action of oxygen on the unsaturated acids produced during hydrolysis. Oxygen adds on to the double bonds to give unstable peroxide compounds, which decompose to form monoxides and active oxygen. The oxygen may add on to some of the peroxide forming unstable ozonides which, in turn, decompose forming aldehyde and ketone compounds. The reactions may be represented—

(1)



Oleic acid residue | Peroxide | Monoxide | Active Oxygen

(2)



Peroxide Ozonide Aldehyde (or Ketone) and Acid

This type of oxidative rancidity is catalysed by light, heat, moisture and the presence of heavy metals, particularly copper ; also, by the peroxides and free fatty acids, when the process is called autoxidation. The products confer a tallowy or " cardboard " flavour upon milk, dried milk, butter and other food fats.

Absorption of oxygen by the double bonds accounts for the use of linseed oil in making paints and treating wood surfaces, and oils which harden on exposure to the atmosphere are called drying oils as distinct from the more saturated non-drying oils and semi-drying oils.

The function of fats in animal nutrition

The prime function of fats and oils in animal nutrition is to provide energy, which they do more effectively than any other food constituents, for one pound produces as much energy as 2·3 lb of carbohydrates. After digestion and absorption they are used to provide heat energy to maintain body temperature, as energy expended in doing physical work, or in the production of animal fat and milk fat.

Some oils are particularly valuable because they contain vitamins A and D. Fish liver oils, especially those of the halibut and cod, are very rich sources of both vitamins, which are also present in butter. The amounts present in butter fat depend on the season of the year and the food consumed by the cow (see Chapter 5).

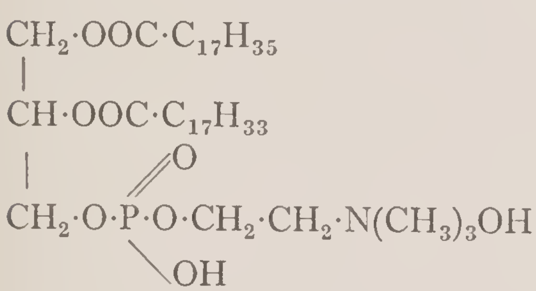
Despite the ease with which animals are able to synthesise fats from carbohydrates, a certain minimum of fat is essential in the diet, for deficiency reduces the digestibility of the food. On the other hand, excess —unlikely in the diet of farm animals—produces nausea and loss of appetite, and the fatty acids produced in the intestines may act as irritants. Furthermore, as a result of researches carried out since 1930, it now appears that certain unsaturated fatty acids are of more importance in animal nutrition than others, for it was found that rats could not be reared in a healthy condition unless the diet contained linoleic, linolenic or arachidonic acids. It also appears that either of these will suffice as they are mutually replaceable. These acids are referred to as " essential fatty acids, " because the animal appears to be incapable of synthesising them from others present in the diet and, in this respect, they are analogous to the

" essential amino acids " (p. 27). Further work is necessary, however, to elucidate the true significance of these indispensable unsaturated acids.

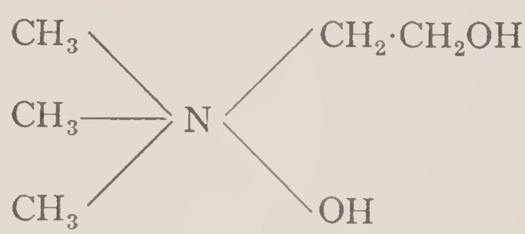
Fatty acids occur in two further types of compounds to which brief reference will be made, namely, waxes, and phospholipins, phospholipides or phosphatides.

Waxes are compounds differing from fats in that the fatty acids are combined with higher alcohols mainly monohydric in nature, e.g., spermaceti consists of cetyl alcohol $C_{16}H_{33}OH$ combined with palmitic acid. Other alcohols found in waxes are myricyl alcohol $C_{30}H_{61}OH$ (in beeswax), and cholesterol $C_{27}H_{45}OH$ (in lanolin or wool wax). Despite a superficial resemblance to fats, waxes are quite different chemically and of little importance in nutrition.

Phospholipides (*phospholipins*, *phosphatides*), on the other hand, bear a much closer resemblance to fats and include lecithins, kephalins and sphingomyelins. On complete hydrolysis lecithins yield glycerol, fatty acids, phosphoric acid and a nitrogenous base choline, a substituted ammonium hydroxide. The glycerol is esterified with one saturated and one unsaturated fatty acid, the third hydroxyl group being attached to phosphoric acid which, in turn, is linked to choline—



Lecithin



Choline

In addition to the stearic and oleic acids included in the above formula, palmitic, linoleic, linolenic, arachidonic and other acids are found in natural lecithins. Egg yolk contains about 10 per cent of lecithin and blood about 2 per cent.

Kephalins differ from lecithins only in the nature of the nitrogenous base, in this case cholamine or amino-ethyl alcohol $NH_2{\cdot}CH_2{\cdot}CH_2OH$. They are essential to the clotting of blood and occur in close association with lecithins. Sphingomyelins are rather more complex but, like the lecithins, they yield on hydrolysis fatty acids, phosphoric acid and choline. Instead of glycerol they contain a second nitrogenous base sphingosine, $CH_3{\cdot}(CH_2)_{12}{\cdot}CH{=}CH{\cdot}CH(NH_2){\cdot}CHOH{\cdot}CH_2OH$, a dihydroxy-amino-alcohol.

Phospholipides occur in plant and animal cells, and in abundance in brain, heart, kidneys, eggs and soya-beans. They are extracted with

alcohol or ether, and are precipitated from solution by adding acetone their sparing solubility in this solvent being used to separate them from the true fats which remain in solution. Phosphatides perform a very important function in the metabolism of fats, for it appears that the fatty acids are transported in the blood stream in this form prior to undergoing oxidation in the liver. It is significant that they are readily miscible with blood plasma.

CHAPTER 2

THE CARBOHYDRATES

THE carbohydrates differ from fats and proteins in being far more widely distributed in plants than in animals, and some of the most important members are confined entirely to vegetable sources. They include starches, sugars and cellulose, by far the most important carbohydrates from the nutritional point of view. It must be realised, however, that many other types of compounds are included in this group, such as gums, mucilages and pectins.

Classification of the carbohydrates is based upon their behaviour on hydrolysis with mineral acids or enzymes (Chapter 6). The simplest members, or monosaccharides, comprise compounds containing 2 to 9 carbon atoms, namely bioses, trioses, tetroses, pentoses, hexoses, heptoses, octoses and nonoses. Of these, the pentoses and hexoses are by far the most important monosaccharide sugars. Condensation of two molecules of a monosaccharide produces one molecule of a disaccharide and, conversely, this yields two monosaccharide molecules on hydrolysis. Similarly trisaccharides are hydrolysed to three monosaccharides, while polysaccharides yield an unknown number of such molecules.

Monosaccharides or monosaccharoses

Pentoses ($C_5H_{10}O_5$) are produced as hydrolysis products of gums, for example, arabinose from the araban of gum arabic ; xylose is similarly obtained from the xylan of hay, oat hulls and many kinds of wood, and ribose occurs in certain nucleic acids and in riboflavin (p. 45). The hexoses, of general formula $C_6H_{12}O_6$, are widely distributed in fruits and honey as glucose (dextrose, grape sugar) and fructose (laevulose, fruit sugar) : a third member galactose is produced in the hydrolysis of lactose (milk sugar).

As a group, the monosaccharides have strong reducing properties. When boiled with Fehling's solution (produced by adding a solution of copper sulphate to an equal volume of a solution containing sodium hydroxide and sodium potassium tartrate—Rochelle salt), the cupric copper is reduced to cuprous oxide which forms a brick red precipitate Cu_2O. This reaction forms the basis of important volumetric and gravimetric methods for the estimation of sugars generally. Similarly, ammoniacal silver nitrate (produced by adding dilute ammonia to a solution of silver nitrate until the precipitate first formed is just redissolved)

is reduced to metallic silver on warming with the sugar in a water bath, when the silver forms a mirror on the sides of the test-tube.

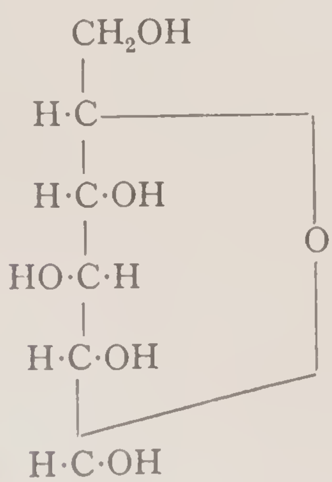
Glucose and fructose may be represented as follows—

Glucose	Fructose
CHO	CH_2OH
|	|
$(CHOH)_4$	CO
|	|
CH_2OH	$(CHOH)_3$
	|
	CH_2OH

Thus glucose is regarded as an aldehydic sugar or aldose, and fructose as a ketose. Ketones, however, do not possess the above reducing properties, and the reducing action of fructose is attributed to the easily oxidisable property of the $—CO{\cdot}CH_2OH$ group.

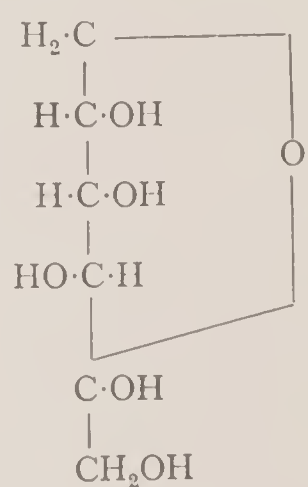
Although the above formulae represent the aldehydic and ketonic nature of glucose and fructose, they do not adequately explain all their properties. Thus glucose is less reactive than one would expect from the above formula, and, for this reason, is regarded as possessing a potential aldehyde group whose reducing power has been masked by linkage with a hydroxyl group with the formation of a ring. It is now known that both glucose and fructose possess ring structures which may be expressed as in 1 and 2 or, more correctly, as in 3 and 4 where the atoms are evenly spaced.

(1)



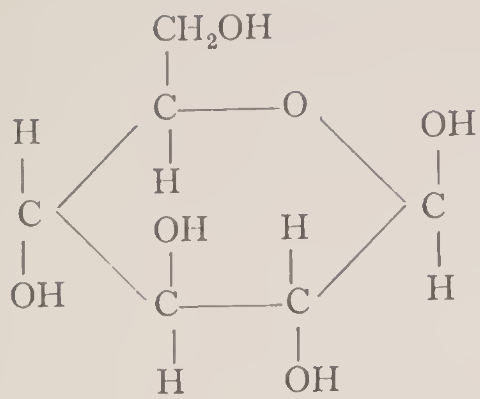
Glucose

(2)

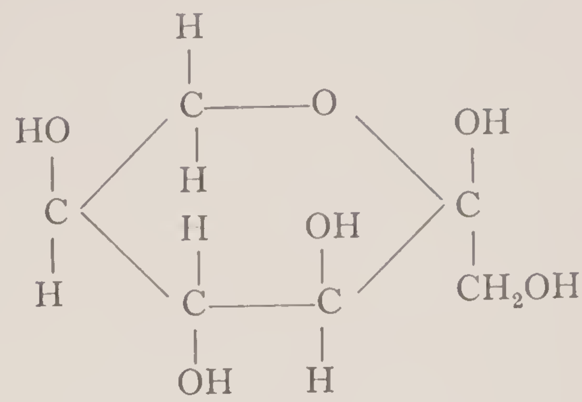


Fructose

(3)



(4)



Disaccharides or disaccharoses

These sugars have the general formula $C_{12}H_{22}O_{11}$ and are produced by the condensation of two hexose molecules. The reaction is reversible and may be represented—

$$C_{12}H_{22}O_{11}+H_2O \rightleftarrows C_6H_{12}O_6+C_6H_{12}O_6$$

Sucrose (cane sugar)	Glucose	Fructose
Maltose (malt sugar)	Glucose	Glucose
Lactose (milk sugar)	Glucose	Galactose

The mixture of glucose and fructose obtained by the hydrolysis of sucrose is known as " invert sugar."

Sucrose, present in sugar cane, sugar beet, mangolds and ripe fruits, is non-reducing, whereas maltose obtained by diastatic hydrolysis of starch, and lactose of milk, both reduce Fehling's solution. It is evident, therefore, that the linkage of glucose and fructose to form sucrose involves a destruction of the potential aldehyde and ketone groups of these sugars. Furthermore, although maltose and lactose reduce Fehling's solution, they have less powerful reducing action than equal weights of their constituent monosaccharides, and this suggests that one of the latter in each case has lost its aldehyde or ketone group. These facts have been taken into account in the structural formulae generally given to the disaccharide sugars.

Of the above three disaccharides, lactose is far less sweet and much less soluble than sucrose and maltose, and maltose is less sweet than sucrose. Just as fructose and glucose may condense to form a disaccharide sucrose, these monosaccharides will form a further condensation product with galactose to give raffinose, a member of the trisaccharide group of sugars of general formula $C_{18}H_{32}O_{16}$. Raffinose, present in sugar beet and cotton-seed, first undergoes hydrolysis to fructose and melibiose, a disaccharide isomeric with lactose ; further hydrolysis yields glucose and galactose.

Polysaccharides

As the name implies the members of this group are condensation products of a large number of monosaccharide units. Starch, for example, on hydrolysis first yields soluble starch, then progressively dextrin, maltose and glucose.

The members of this group are comparatively unreactive substances which form colloidal solutions, and are quantitatively the most important nutrients in feeding-stuffs of vegetable origin. In this group are the hexosans $(C_6H_{10}O_5)_n$ including starch, dextrins, glycogen, inulin and cellulose, and the pentosans $(C_5H_8O_4)_n$ araban and xylan which on hydrolysis yield pentoses.

Until comparatively recent years little was known regarding the structure of polysaccharides but, during the last decade or so, mainly due to the work of Haworth and his associates, considerably more information has been obtained. Thus it appears that glycogen, the simplest member, contains about 12 α-glucose units and has a molecular weight of approximately 2000. Starch contains at least two substances called amylose (soluble starch) and amylopectin, which contain 24 to 30 α-glucose units with molecular weights of 4000-5000. It has been estimated that cellulose contains 100–200 β-glucose units and has a molecular weight of 20,000–40,000. Inulin is similarly composed of about 30 fructose units and has a molecular weight of about 5000.

The polysaccharides may be regarded as consisting of long chains of monosaccharide units. They form some of the most important reserve materials of plants. Starch is widely distributed in tubers and cereal grains, where its presence may be readily demonstrated by the typical blue-black colour which it gives with a cold dilute solution of iodine. It occurs in the form of granules varying in size and shape according to the plants in which they are found, for instance, potatoes, peas, wheat and oats. This property is used when identifying food-stuffs by microscopic examination. In certain plants, notably the Jerusalem artichoke, its place as a reserve material is taken by inulin, which on hydrolysis yields fructose.

Glycogen forms the reserve carbohydrate of animal liver, and is sometimes called " animal starch." Like starch it yields glucose on hydrolysis, but with iodine gives a brown colour.

Cellulose is the chief constituent of the structural framework of plants and the protective coverings of seeds. It occurs in association with lignin as lignocellulose. Lignin is a substance of unknown constitution, but contains an aromatic nucleus with hydroxy and methoxy (CH_3O-) groups attached. It confers resistant properties on the cellulose, thereby fitting it for its structural and protective functions. Cellulose is only slowly hydrolysed by hot dilute acids and alkalies, and is unattacked by the

enzymes of the digestive system. It dissolves in an ammoniacal solution of copper (Schweitzer's reagent).

The foregoing classification of the carbohydrates may be summarised as follows—

- I SUGARS ...
  - *Monosaccharides*
    - *Pentoses* $C_5H_{10}O_5$
      Arabinose, ribose, xylose
    - *Hexoses* $C_6H_{12}O_6$
      Glucose, fructose, galactose
  - *Disaccharides* $C_{12}H_{22}O_{11}$
    Sucrose, maltose, lactose
  - *Trisaccharides* $C_{18}H_{32}O_{16}$
    Raffinose
- II NON-SUGARS or POLYSACCHARIDES
  - *Pentosans* $(C_5H_8O_4)n$
    Araban and xylan
  - *Hexosans* $(C_6H_{10}O_5)n$
    Starch, glycogen, cellulose, inulin
- III MIXED POLYSACCHARIDES ... Gums, mucilages and pectins

The function of carbohydrates

In function the carbohydrates resemble fats ; in the animal body they are oxidised to produce energy, or may be converted into reserve fat. Surplus carbohydrates, which after digestion are largely in the form of glucose, are also converted into glycogen in the liver which, by alternate synthesis and breakdown of glycogen, controls the concentration of glucose in the blood. If present in inadequate amounts the animal may use protein as a source of energy. In order to avoid this, abundant carbohydrates should be supplied, for protein is a relatively expensive constituent and its use for this purpose is uneconomical. A sufficiency of fibre too is essential for, although lignified cellulose is largely unavailable, it helps to satisfy the appetite, and aids digestion by opening up the mass of more concentrated foods which, in its absence, may form a compact indigestible mass in the stomach. When deprived of sufficient bulk animals recourse to eating dirt, sand, manure and rags.

Crude fibre and soluble carbohydrates

In assessing the nutritive value of foods it is customary to express the total carbohydrates as crude fibre and soluble carbohydrates. The former is crude cellulose, the residue which remains after the food has been boiled for 30 minutes with dilute sulphuric acid and then with dilute

sodium hydroxide solution (each containing 1·25 grams per 100 ml of solution). The " soluble carbohydrates " or nitrogen-free extractives are estimated by difference, by subtracting from 100 the sum of the percentages of moisture, crude protein, ether extract, crude fibre and ash. They include some cellulose and lignin rendered soluble in the determination of fibre ; the distinction between crude fibre and soluble carbohydrates is thus purely arbitrary, but it is convenient nevertheless.

The glucosides

Before leaving the carbohydrates it may be well to mention a group of substances which contain glucose as one of their components. Their function is protective rather than nutritive, for their chemical nature is such as to make the plants containing them poisonous or very unpalatable to animals.

There are two important types. Those of the first type, the cyanogenetic or cyanophoric glucosides, yield on hydrolysis with enzymes or dilute acids, glucose, an aldehyde or ketone, and hydrocyanic acid. One of the most important examples is phaseolunatin or linamarin, present in linseed, cassava and the Java bean *Phaseolus lunatus*, where it occurs in conjunction with the enzyme phaseolunatase. When crushed linseed is kept moist and warm the glucoside undergoes hydrolysis to give glucose, acetone and HCN. It is for this reason that linseed, either alone or as a constituent of meals, must be prepared with great care for animal consumption, especially in the case of young calves, which are particularly sensitive to "linseed poisoning," although older stock are apparently less affected. Such meals are usually fed to calves in the form of gruel and, in order to destroy the enzyme, it is essential that the water used should be boiling ; it is probably safest to boil the gruel for about 10 minutes. Allowing the meal to steep under warm conditions is to court disaster because of the hydrocyanic acid produced (see "Linseed cake and meal," Chapter 11).

Although of less importance, amygdalin, found in bitter almonds and in the kernels of rosaceous and prunaceous fruits, e.g., peaches and plums, is a substance of bitter taste which yields glucose, benzaldehyde and HCN when hydrolysed by the accompanying enzyme emulsin. This enzyme also hydrolyses dhurrin of millet (*Sorghum vulgare*) to glucose, *p*-hydroxybenzaldehyde and HCN.

Glucosides of the second type, the mustard-oil glucosides, possess a very pungent smell and taste, and occur in such cruciferous crops as black and white mustard. The sinigrin of black mustard is hydrolysed by myrosin to glucose, allylisothiocyanate (C_3H_5CNS) and potassium hydrogen sulphate. Allylisothiocyanate or mustard oil has a pronounced pungent taste and smell, and probably protects plants against fungoid,

bacterial and insect attack. The pungent taste of mustard is due to this substance. Instances have been recorded where cattle consuming cake contaminated with crushed seeds of black mustard showed symptoms of irritant poisoning, namely, intense colic, restlessness, frantic rushing about and mania with consequent exhaustion and collapse. Whole seeds are apparently without effect and pass unaltered into the faeces.

CHAPTER 3

THE PROTEINS

PROTEINS are the chemical foundations of all living matter. With water, they form the material out of which the protoplasm of both animal and plant cells is built, and their presence is intimately connected with the cycles of chemical and physico-chemical changes that go to form the life of the cell. In addition to their importance in this respect, they are accumulated in eggs, seeds and secretions such as milk intended as food for the young organism. Many materials of very diverse nature are composed mainly of protein, e.g., flesh, egg-albumin, milk caseinogen, wheat gluten, gelatin and the protective tissues, hair, wool, nails, hoofs, horns and feathers.

Composition and characteristics

All proteins contain carbon (51–55 per cent), oxygen (20–30 per cent), nitrogen (15–17 per cent), and hydrogen (about 7 per cent), while some contain sulphur (0·4–2·5 per cent) and/or phosphorus (0·1–1·0 per cent).

The large majority of proteins form colloidal solutions in water, a few are insoluble, and many have been prepared in the crystalline form, e.g., haemoglobin. An explanation of the great differences in the properties of various proteins must be sought in the chemical units from which proteins are built, for their nature, number and arrangement in pattern account for the appearance and properties of any given type of protein. These units are called amino-acids and have the general formula $R{\cdot}CHNH_2COOH$, where R represents residues derived from alkyl groups such as methyl (CH_3) and ethyl (C_2H_5), and may also contain ring structures as shown in the formulae given below. The presence of the carboxylic and amino groups confers acidic and basic properties on the molecule, and amino-acids are, therefore, amphoteric in nature.

Proteins contain from 20 to 25 different amino-acids. The simplest member is amino-acetic acid or glycine, derived from acetic acid by replacement of one of the alkyl hydrogen atoms by the amino group ($—NH_2$)—

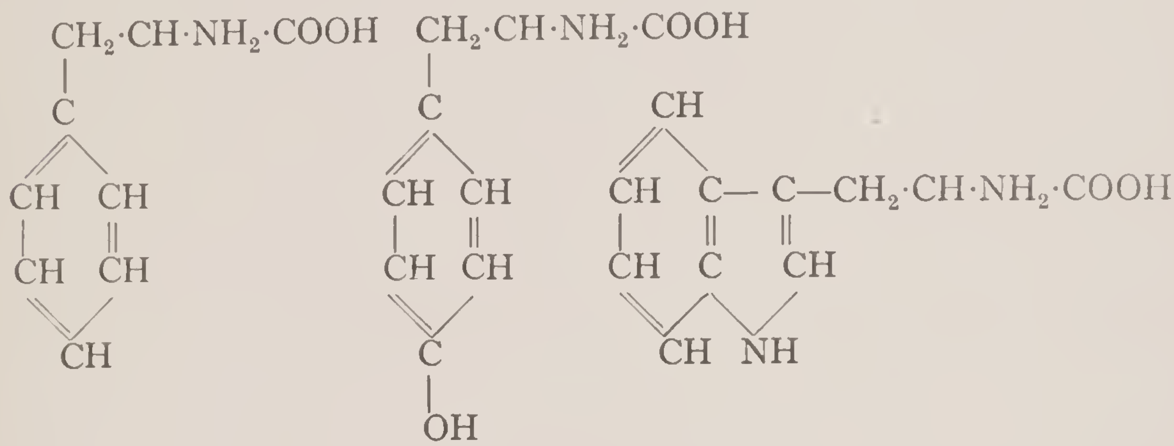
$CH_3{\cdot}COOH$	$CH_2NH_2{\cdot}COOH$
Acetic acid	Amino-acetic acid or glycine

Similarly alanine, amino-propionic acid, is derived from propionic acid $CH_3{\cdot}CH_2{\cdot}COOH$—

$$CH_3{\cdot}CH{\cdot}NH_2{\cdot}COOH$$

Alanine (Amino-propionic acid)

By further substitution in the alkyl group, benzene and other aromatic groups can be introduced, and a number of important amino-acids may be regarded as derivatives of propionic acid. Phenylalanine, tyrosine and tryptophan are examples of this type of amino-acid, and others are given in the next section—



Phenylalanine Tyrosine Tryptophan

By designating the carbon atom next to the carboxyl group (COOH) the α-carbon atom, phenylalanine becomes α-amino β-phenyl propionic acid; similarly tyrosine is α-amino β-hydroxyphenyl propionic acid, and tryptophan is α-amino β-indole propionic acid.

Amino-acids are obtained from proteins by hydrolysis with acids, alkalies or enzymes, and the process of separation is a difficult one. It has been shown that 22 amino-acids occur in typical food proteins. They are classified according to the number of amino and carboxylic groups present, and also into a group containing ring structures other than benzene.

Classification of the amino-acids

1. *Monoamino—monocarboxylic acids*

Glycine, amino-acetic acid. $CH_2\cdot(NH_2)\cdot COOH$.

Alanine, α-amino-propionic acid. $CH_3\cdot CH(NH_2)\cdot COOH$.

Valine, α-amino-isovalerianic acid. $\begin{matrix}CH_3\\CH_3\end{matrix}\rangle CH\cdot CH(NH_2)\cdot COOH$.

Leucine, α-amino-isocaproic acid. $\begin{matrix}CH_3\\CH_3\end{matrix}\rangle CH\cdot CH_2\cdot CH(NH_2)\cdot COOH$.

Isoleucine, α-amino β-methyl-β-ethyl propionic acid. $\begin{matrix}CH_3\\C_2H_5\end{matrix}\rangle CH\cdot CH(NH_2)\cdot COOH$.

Norleucine, α-amino-caproic acid. $CH_3\cdot CH_2\cdot CH_2\cdot CH_2\cdot CH(NH_2)\cdot COOH$

Phenylalanine, α-amino-β-phenyl propionic acid.	$C_6H_5 \cdot CH_2 \cdot CH(NH_2) \cdot COOH.$
Tyrosine, α-amino-β-*p*-hydroxyphenyl propionic acid.	$HO \cdot C_6H_4 \cdot CH_2 \cdot CH(NH_2) \cdot COOH.$
Serine, α-amino-β-hydroxy propionic acid.	$CH_2OH \cdot CH(NH_2) \cdot COOH.$
Threonine, α-amino-β-hydroxybutyric acid.	$CH_3 \cdot CHOH \cdot CH(NH_2) \cdot COOH.$
Cysteine, α-amino-β-thiopropionic acid.	$CH_2 \cdot SH \cdot CH(NH_2) \cdot COOH.$
Cystine or di-cysteine (Diamino-dicarboxylic acid).	$\begin{array}{l} S \cdot CH_2 \cdot CH(NH_2) \cdot COOH. \\ \vert \\ S \cdot CH_2 \cdot CH(NH_2) \cdot COOH. \end{array}$
Methionine, α-amino-γ-methylthiol-butyric acid.	$CH_3 \cdot S \cdot CH_2 \cdot CH_2 \cdot CH(NH_2) \cdot COOH.$

2. *Monoamino-dicarboxylic acids.*

Aspartic acid, α-amino-succinic acid.	$\begin{array}{l} CH_2 \cdot COOH. \\ \vert \\ CH(NH_2) \cdot COOH. \end{array}$
Glutamic acid, α-amino-glutaric acid.	$HOOC \cdot CH_2 \cdot CH_2 \cdot CH(NH_2) \cdot COOH.$
Hydroxyglutamic acid, α-amino-β-hydroxyglutaric acid.	$HOOC \cdot CH_2 \cdot CHOH \cdot CH(NH_2) \cdot COOH.$

3. *Diamino-monocarboxylic acids.*

Arginine, α-amino-δ-guanidovaleric acid.

$$HN{=}C \cdot NH_2 \cdot NH \cdot CH_2 \cdot CH_2 \cdot CH_2 \cdot CH(NH_2) \cdot COOH.$$

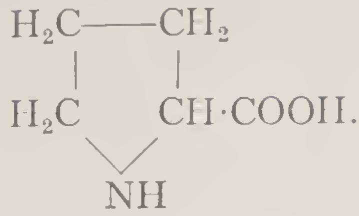
Lysine, α-ε-diamino-caproic acid.

$$CH_2(NH_2) \cdot CH_2 \cdot CH_2 \cdot CH_2 \cdot CH(NH_2) \cdot COOH.$$

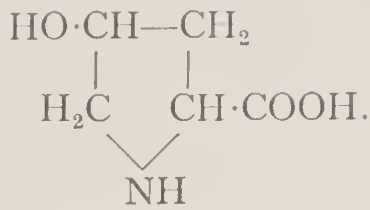
4. *Heterocyclic amino-acids*

Histidine, α-amino-β-iminazole-propionic acid.

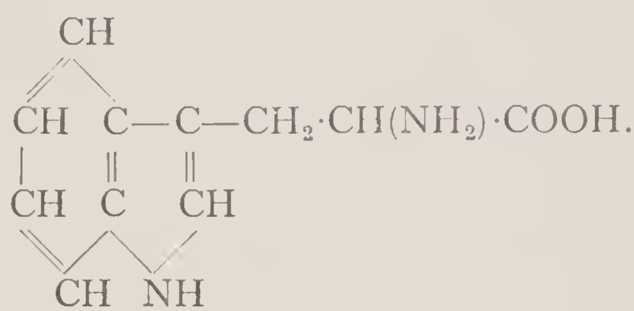
Proline, α-pyrrolidine-carboxylic acid.



Hydroxyproline, γ-hydroxy-α-pyrrolidine carboxylic acid.



Tryptophan, α-amino-β-indole-propionic acid.



It is noteworthy that all amino-acids present in proteins are α-amino-acids. They are crystalline, colourless substances, generally soluble in water with the exception of tyrosine and cystine, and in dilute acids and alkalies. The method of union illustrates their amphoteric nature, for the amino group of one molecule unites with the carboxyl group of the other—

$$\underset{\text{Glycine}}{H_2N\cdot CH_2\cdot CO}\boxed{OH + H\cdot}\underset{\text{Glycine}}{NH\cdot CH_2\cdot COOH} = \underset{\text{Glycyl-glycine}}{H_2N\cdot CH_2\cdot CO\cdot NH\cdot CH_2\cdot COOH} + H_2O$$

This type of linkage involving the formation of $-\overset{\overset{\large O}{\|}}{C}-NH-$ is known as the peptide linkage, and glycyl-glycine is a dipeptide. Similarly, di-, tri-, tetra-peptides, etc., may be formed consisting of the same or different amino-acids. Thus di-glycyl glycine contains 4 glycine units, while three different units are combined in the tetra-peptide glycyl-alanyl-glycyl-tyrosine.

Peptides containing several amino-acid units are called polypeptides, and Emil Fischer succeeded in synthesising an octadecapeptide containing 3 leucine and 15 glycine units. The condensation of a large number of amino-acids gives proteins their colloidal properties and confers great complexity upon the molecule. All attempts at synthesis have failed,

probably due to lack of knowledge regarding the arrangement of the various units in the molecule and the great practical difficulties involved. Until recently, little was known about the molecular weights of proteins, but the application of Svedberg's method of measuring sedimentation velocities in the ultracentrifuge enabled approximate values to be obtained, e.g., lactalbumin 18,000, egg albumin 40,000, pepsin 35,000 and virus proteins with values of many millions.

Reference has already been made to the fact that the properties of a protein will depend on the nature of the amino-acids present as well as on the number and mode of arrangement. This is illustrated in a striking manner by the response which certain proteins give to a series of colour reactions used to characterise this group of substances.

Colour reactions of proteins

1. *The biuret test.*—A small quantity of protein, e.g., caseinogen, is shaken with a little sodium hydroxide solution, and then with copper sulphate solution added drop by drop until a violet colour appears. The reaction depends upon the presence of two or more peptide linkages (—CO—NH—), and is also given by certain non-protein substances, e.g., oxamide, biuret and peptides.

$$\begin{array}{l} CO{\cdot}NH_2 \\ | \\ CO{\cdot}NH_2 \end{array} \qquad\qquad \begin{array}{l} CO{\cdot}NH_2 \\ | \\ NH \\ | \\ CO{\cdot}NH_2 \end{array}$$

Oxamide   Biuret

2. *The xanthoproteic test* is given by proteins containing tyrosine and tryptophan groups. It consists in warming a protein solution with a little concentrated nitric acid. The precipitate first formed turns yellow, and on adding excess ammonia or sodium hydroxide becomes orange. This reaction occurs when nitric acid comes into contact with skin, and the yellow stain darkens to an orange colour when ammonia is applied. It is due to the formation of aromatic nitro-compounds from amino-acids containing the benzene nucleus.

3. *Millon's test.*—When Millon's reagent is added to a protein solution a white precipitate is formed which turns red on heating. This reaction too indicates the presence of tyrosine. Millon's reagent is prepared by dissolving mercury in twice its weight of concentrated nitric acid and diluting with an equal volume of water. It contains mercuric and mercurous nitrates and nitrous acid.

4. *Adamkiewicz test.*—Excess of glacial acetic acid is added to the solution containing the protein, and concentrated sulphuric acid poured

carefully down the side of the test-tube. A reddish-violet ring appears at the junction of the liquids. The reaction is due to the presence of tryptophan, and is only obtained when the acetic acid contains glyoxalic acid (COOH·CHO). It may be prepared by reducing a saturated aqueous solution of oxalic acid with magnesium, and used instead of, or added to the acetic acid.

5. *Sulphur test*.—On adding a drop of lead acetate solution to a protein solution a precipitate is formed. This is dissolved by the addition of sufficient sodium hydroxide solution, when a black colour develops, due to the reaction of the lead acetate with hydrogen sulphide formed from the cystine unit.

Not all proteins respond equally to the above tests. Gelatin gives only a very faint response to the xanthoproteic, Millon, Adamkiewicz and sulphur reactions, because it lacks tryptophan and contains very little tyrosine, while zein of maize lacks tryptophan but contains considerable amounts of tyrosine. The colour reactions afford a useful qualitative means of detecting the presence or absence of certain important amino-acid groups in a protein.

Coagulation and precipitation reactions

The coagulation and precipitation of proteins under certain conditions and by various reagents are important reactions. Familiar examples of the coagulation of proteins by heat are the setting of egg-albumin, and the formation of a skin containing lactalbumin on the surface of milk at the boiling point of water. The presence of albumin in urine is also detected by heating filtered urine after the addition of a little NaCl. Many proteins may be coagulated by adding alcohol, concentrated mineral acids or concentrated solutions of certain salts (see below). Proteins are precipitated from solution by forming compounds with salts of heavy metals, e.g., mercuric chloride and nitrate, copper sulphate, ferric chloride, zinc and lead acetate and basic lead acetate. Solutions of these salts are extensively used to clarify opaque liquids prior to the determination of sugars. Acid mercuric nitrate, zinc acetate and copper sulphate are used to precipitate the proteins and fat of milk in determinations of lactose by volumetric and gravimetric methods using Fehling's solution, and by polarimetric methods. The lead acetates are employed to clarify molasses and sugar beet extracts for polarimetric work.

Proteins also form precipitates with alkaloidal reagents, i.e., reagents used to precipitate alkaloids. Among these are sulphosalicylic, picric, tannic, phosphotungstic and trichloroacetic acids. Sulphosalicylic acid is used to detect albumin in urine. The manufacture of leather depends upon the combination of tannic acid with the protein of animal hides, and these reagents are also employed in removing proteins from blood and

other fluids prior to analysis. In the determination of albumin in milk this protein is precipitated by the combined action of heat and trichloroacetic acid.

The coagulation of proteins is used, together with certain special characteristics, as a basis of classification.

Classification of the proteins

A. Simple proteins yield only amino-acids or their derivatives on hydrolysis. They include the following groups—

(*a*) *Albumins* are soluble in water and dilute salt solutions but coagulated by heat, saturated ammonium sulphate and acids. They are abundant in animal tissues and plants. Egg albumin, albumin of blood serum, lactalbumin, wheat leucosin and pea legumelin are common examples.

(*b*) *Globulins* are insoluble in water, soluble in dilute salt solutions and are coagulated by heat, saturation with NaCl or $MgSO_4$, and by half saturation with ammonium sulphate. They include globulin of muscle and blood serum, edestin of hemp, phaseolin of beans, and legumin of peas and beans.

Albumins and globulins are sometimes called the coagulable proteins, and can be separated from all other proteins which do not possess the property of heat coagulation.

(*c*) *Glutelins* are insoluble in water and alcohol, but dissolve in dilute acids and alkalies. Wheat glutenin and oryzenin of rice are examples.

(*d*) *Prolamins* are insoluble in water, dilute acids, alkalies or salt solutions, dissolve in 70-80 per cent alcohol, and include gliadin (wheat), hordein (barley) and zein (maize). They are exclusively plant proteins.

(*e*) *Scleroproteins*, sometimes called albuminoids, form skeletal structures and protective tissues, e.g., ossein of bone, collagen and keratin of hair, horn and feathers, gelatin (formed on boiling collagen with water), and elastin of the tendons. In general they are insoluble in most reagents (except gelatin).

(*f*) *Protamins and histones* are strongly basic and limited in distribution, e.g., in the spermatozoa and roes of fish. Globin of haemoglobin is an important histone. Both groups are soluble in water, but histones are the only proteins precipitated by ammonia.

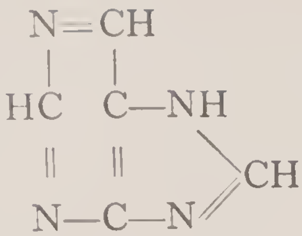
B. Conjugated proteins.—This group includes several types of very complex compounds, for in them the protein molecule, itself complex, is combined with other molecules. They are soluble in dilute alkalies, but insoluble in water and dilute acids.

(*a*) *Nucleoproteins* contain simple proteins combined with nucleic acids which, according to the generally accepted view, are composed of units containing four nucleotides. A nucleotide contains phosphoric acid,

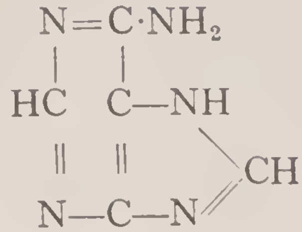
a pentose sugar and a purine or pyrimidine base, and four nucleotides combined together form a tetranucleotide. It was thought that only two nucleic acids existed, one derived from plants and one from animals. They were called " yeast " and " thymus " nucleic acids respectively, in virtue of the sources from which they were originally obtained. Both contain phosphoric acid and the bases adenine, guanine and cytosine, but differ in the nature of the fourth base and the sugar, yeast nucleic acid containing the base uracil and the sugar ribose $C_5H_{10}O_5$ whereas thymonucleic acid contains thymine and desoxyribose $C_5H_{10}O_4$. The following serve to illustrate the difference in the tetranucleotide units involved—

Yeast nucleic acid	*Thymonucleic acid*
Phosphoric acid—ribose—uracil	Phosphoric acid—desoxyribose—thymine
Phosphoric acid—ribose—adenine	Phosphoric acid—desoxyribose—adenine
Phosphoric acid—ribose—cytosine	Phosphoric acid—desoxyribose—cytosine
Phosphoric acid—ribose—guanine	Phosphoric acid—desoxyribose—guanine

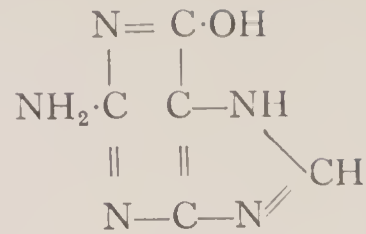
The idea that yeast and thymus nucleic acids are confined to plants and animals respectively has now been abandoned. It now appears that the former, ribonucleic acid, is characteristic of the cytoplasm and the nucleolus of both plant and animal cells, whereas desoxyribose nucleic acid is characteristic of the chromosomes of the nucleus. The latter exists in the form of highly polymerised tetranucleotides, whereas a much lower degree of polymerisation is apparent in ribonucleic acid. They are referred to as ribose and desoxyribose polynucleotides, and also occur in combination with phospholipins as phospholipin-nucleoprotein complexes. It is now apparent that nucleic acids are associated with all reproductive processes involving cells, viruses or other self-perpetuating elements within the cell. Evidence is accumulating that the type of growth is related to nucleic acid metabolism, and when this is excessive growth becomes uncontrolled, when deficient, growth is stunted. The formulae of the most important purine and pyrimidine bases are presented below. The former are amino derivatives of the 2-ring compound purine containing a six- and a five-membered ring—



Purine

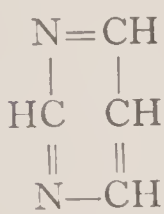


Adenine

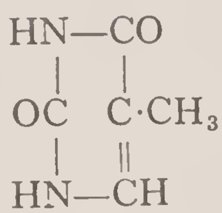


Guanine

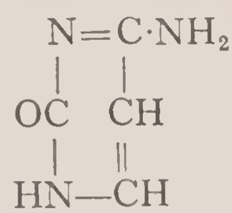
Similarly pyrimidine bases are derived from pyrimidine the 6-membered ring of purine. They have the following structures—



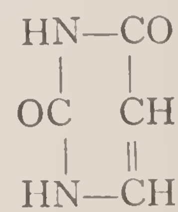
Pyrimidine



Thymine



Cytosine



Uracil

Nucleoproteins have been dealt with in some detail, for they are among the most complex compounds of plant and animal tissues, and serve well to emphasise the complexity of conjugated proteins. Only brief reference will be made to the other types.

(*b*) *Chromoproteins* include the very important haemoglobin of blood, in which the protein globin is combined with the colouring matter haematin, containing iron.

(*c*) *Phosphoproteins* are compounds of proteins and phosphoric acid, examples being caseinogen, the principal protein of milk, and ovovitellin of egg-yolk. They form the greater part of the protein in the food of young mammals and embryo birds.

(*d*) *Gluco or Glyco-proteins* contain a carbohydrate group in addition to protein. Mucin, which imparts sliminess to mucous secretions, is an example.

(*e*) *Lecithoproteins* contain protein combined with lecithins or related substances (see Chapter 2).

C. Derived proteins may be regarded as being rather simpler in nature than proteins from which they are produced by the action of acids, alkalies or enzymes. They include the following groups, in descending order of complexity—

Primary derivatives are formed by hydrolysis involving only slight changes.

Thus *Proteans* include casein of curdled milk and fibrin of coagulated blood ; *meta-proteins* result from further hydrolysis giving products soluble in dilute acids and alkalies but not in neutral solvents ; *coagulated*

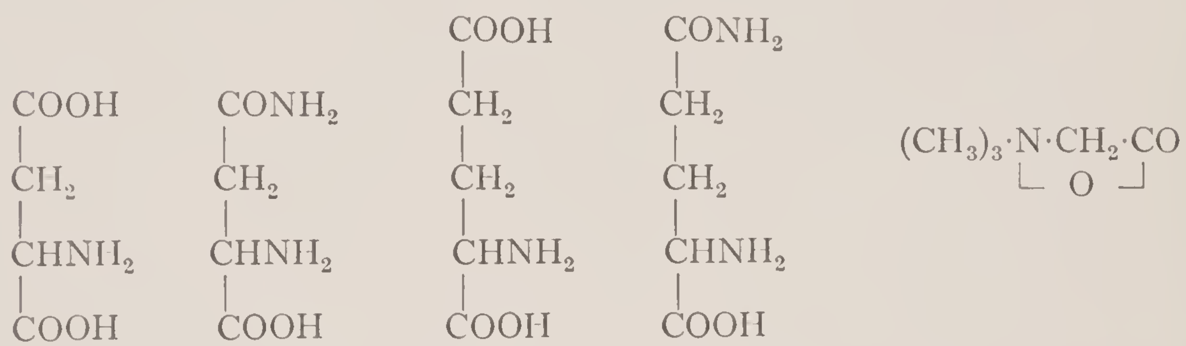
proteins are insoluble products formed by the action of heat or alcohol, e.g., egg albumin, either cooked or precipitated by alcohol.

Secondary derivatives are produced by more pronounced hydrolysis, as evident from their stability under various treatments. Thus *proteoses* are soluble in water, coagulated by saturated ammonium sulphate solution but not by heat. Commercial " peptones " are mainly of this nature. *Peptones* are soluble in water and not coagulated by either of the above treatments. *Peptides* may contain two or more amino-acid units, i.e., in di- and poly-peptides.

The protein content of feeding-stuffs ; crude protein, true protein and amides

Despite the great variety and complexity of proteins, it is a comparatively simple matter to form a useful estimate of the protein content of feeding-stuffs. Reference has already been made to the fact that, on an average, proteins contain 16 per cent of nitrogen. In practice, the total N-content of a feeding-stuff is determined by a modified Kjeldahl method, and this figure multiplied by 100/16 or 6·25 gives the content of " crude protein." It should be remembered that individual proteins vary in N-content, and special factors are used in certain cases, e.g., 5·7 for wheat and flour and 6·38 for milk. The crude protein of feeding stuffs includes non-protein nitrogen, i.e., substances of much simpler nature, and brief reference to the method used to distinguish between protein and non-protein nitrogen may help to illustrate this fact. If a known weight of finely-ground dried grass is boiled with water, and a suitable quantity of a suspension of copper hydroxide in aqueous glycerine is added (Stutzer's reagent), the protein forms a precipitate with the copper hydroxide and may be separated from the non-protein nitrogenous compounds by filtration, the latter passing into the filtrate. The percentage of nitrogen in the residue multiplied by 6·25 gives the " true protein " content, and the difference between this and the " crude protein " is termed the " amide " content, i.e., the amount of non-protein nitrogenous compounds. Young and immature crops are generally rich in amides, as distinct from mature crops, especially roughages. Immature mangolds contain approximately only one-third of their total nitrogen in the form of true protein, two-thirds being amide nitrogen containing a high proportion of nitrate. In fact, this is the reason why mangolds are stored for several months after harvesting ; this allows sufficient time for the conversion of a good deal of nitrate and other amide-N into protein, and is necessary to avoid scouring in stock. Scouring is also noticeable when animals are put out to grass in the spring after a winter diet of more mature foods.

The term " amides " as used in nutrition refers to all non-protein nitrogenous substances including nitrates, ammonium salts, amino-acids and simple peptides, whereas, in organic chemistry, amides, or acid amides, belong to a single class of substances closely related to the fatty acids. One of the simplest examples is acetamide $CH_3CO{\cdot}NH_2$, a derivative of acetic acid CH_3COOH. Among the amides found in plants are asparagine and glutamine derived from aspartic and glutamic acids, two monoamino dicarboxylic acids. They occur in mangolds together with betaine or trimethyl glycine—



Aspartic acid — Asparagine — Glutamic acid — Glutamine — Betaine

The betaine of mangolds and sugar beet products may give rise to a fishy taint in milk. This was thought to be due to the production of trimethylamine $(CH_3)_3N$ but, more probably, trimethylamine oxide $(CH_3)_3NO$ is formed and adds on to the double bonds of unsaturated fatty acids to form compounds with a more pronounced fishy taint than trimethylamine itself.

The function of proteins and amides in nutrition

The derivation of the word " protein " from a Greek word meaning " I am first " is an indication of the pre-eminent part played in nutrition by this group of substances. Whereas plants are able to synthesise protein from such simple inorganic substances as nitrogenous manures, carbon dioxide and water, animals are unable to do so, and are entirely dependent upon plant protein.

Proteins are used chiefly in the building of animal flesh and protective coverings in the form of hair, nails, hoof, horn, wool and feathers, in the formation of eggs and milk, and in forming the digestive juices and other internal secretions.

All proteins, however, are not of equal value from the nutritional point of view, and are said to vary in " quality " or " biological value. " For example, in experiments with rats, it was shown that casein maintained them in a healthy condition and promoted vigorous growth, whereas

gliadin sufficed to maintain the rats but promoted only slight growth, whilst zein neither sufficed for maintenance nor growth.

The reason for such differences in biological value is due to the fact that animals, while able to synthesise many amino-acids from others present in their food, are quite unable to synthesise certain members, or cannot do so rapidly enough to maintain normal growth. These are termed " essential " amino-acids, and include lysine, tryptophan, histidine, phenylalanine, leucine, isoleucine, threonine, methionine, valine and arginine. The protein gliadin is deficient in lysine, and zein lacks lysine and tryptophan.

It is doubtful whether the problem is as simple as this, for cystine, which is listed as a non-essential amino-acid, became essential for the normal nutrition of the rat when the casein provided was reduced to a low level, and it is regarded as a necessary amino-acid in the diet of larger animals. It is possible too that different species of animals vary in their ability to synthesise amino-acids, and that different amino-acids are more important for some functions than others, e.g., cystine for wool production and lysine for milk production.

Generally speaking, proteins which contain all the " essential " amino-acids in suitable proportions are " complete " or " first class proteins," and have a high " biological value," whereas, those lacking one or more of these acids are " incomplete," or " second class," and have a lower " biological value." With the exception of gelatin, all animal proteins are complete, and several plant proteins fall into this class. Gelatin lacks tryptophan, valine and isoleucine, and also contains little or no tyrosine and cystine. The proteins of eggs, milk, fish and " fresh meat " are complete, as are also glycinin of soya-beans, edestin, glutenin and maize glutelin. Most plant proteins are " second class " or " incomplete," and it is of prime importance that herbivorous animals and human vegetarians draw upon protein from a variety of sources, so that the several " incomplete " proteins may supplement one another, and thus provide an adequate protein diet containing the " essential " amino-acids. A survey of the results of research in this connection has been made by Boas-Fixen, and the proteins of various foods placed in the following descending order of biological value ; milk and egg proteins followed closely by meat and fish proteins ; cereal, pulse, and nut proteins.([1]) The biological value will depend upon the extent to which a food supplies the amino-acids in relation to the qualitative and quantitative needs of the animal. Since the requirements for maintenance, growth and milk production vary, so will the biological value of proteins depend to some extent upon

[1]Boas Fixen, M.A., 1935, " The biological value of protein in nutrition," *Nutr. Abstr. Rev.*, 4, p. 447.

the purpose for which they are required. Moreover, it has been shown that the presence of animal proteins, e.g., in skim-milk, increases the value of cereal proteins when these are fed together and it is, therefore, an advantage to include some protein of animal origin in the diet. It should also be remembered that proteins vary in digestibility, so that a low biological value may be compensated to some extent by a high digestibility.

As far as " amides " are concerned, they are generally assumed to possess about half the feeding value of " true protein." There is, however, some evidence suggesting that their value is a good deal higher, partly, at least, because micro-organisms in the rumen of herbivora may assimilate simple nitrogenous compounds such as urea and ammonium salts, and from them synthesise their body protein, which becomes available as " true protein " to the animals on the death of these micro-organisms.

In view of what has been said regarding the function of proteins, it will be obvious that deficiency produces serious results, and a certain minimum is necessary to enable the other food constituents to be digested efficiently. The feeding of excess protein is wasteful, and leads to putrefactive changes with a consequent irritation of the intestines and an accumulation of harmful products.

CHAPTER 4

THE MINERAL OR ASH CONSTITUENTS

The food constituents hitherto described, namely, fats, carbohydrates and proteins, make up, with water, the bulk of a food. Being organic in nature they are almost completely oxidised on ignition, and only such elements as sulphur and phosphorus remain. During the process of ignition, these elements combine with the more basic mineral substances to form salts, and appear in the ash of a food, although originally present in organic combination, e.g., in proteins. It is, therefore, obvious that the compounds found in the ash give no indication of the mode of combination in which these so-called mineral constituents actually exist in the food, where fluorine, chlorine and iodine occur mainly as salts, sulphur mainly in amino-acids and to a limited extent as sulphates, and phosphorus in both organic and inorganic form.

In the first place, it may be said that more than a dozen such elements are essential to normal nutrition, and that with advancing knowledge more may be added. Those known to be essential are sodium, potassium, calcium, magnesium, iron, copper, cobalt, zinc, manganese, phosphorus, sulphur, chlorine, iodine ; others may be present but are not known to be essential for life or growth, namely, silicon, aluminium, nickel, fluorine, bromine, boron, selenium, molybdenum and arsenic. On the contrary, some of them may be harmful, and this also applies to several of the essential elements when present greatly in excess of the animals' requirements. Arsenic is extremely toxic, and copper is harmful except in minute amounts. Fluorine impairs the structure of the teeth, and produces a mottling of the enamel when taken in excessive amounts from drinking water, soil, mineral supplements containing fluorine or other sources. It is, however, a normal constituent of bones and teeth, and may contribute to the hardness of the latter, while deficiency is thought to encourage the development of dental caries. Selenium has been found in harmful amounts in the herbage of certain areas of the Middle and Western United States where " alkali disease " formerly wrongly attributed to alkali in the drinking water, affects horses cattle, sheep and poultry. Loss of vitality, appetite and hair, soreness and sloughing of the hoof, emaciation and anaemia, are symptoms of excess of selenium which may cause death. " Blind staggers," a more acute form, affects cattle causing depraved appetite, defective vision and blindness, paralysis and death. Some species of plants absorb much more selenium than others, and addition of sulphur to the soil appears to retard absorption by plants.

Molybdenum, present in relatively large amounts in some of the pastures of Somerset, causes such severe scouring that animals, particularly milking cows, rapidly lose condition, and the pastures are said to be "teart." Lime and manures containing it increase the amount absorbed, but acidic nitrogenous manures containing ammonium sulphate have the reverse effect. The scouring may be cured by administering up to 1 or 2 grams of copper sulphate daily to sheep and cattle respectively. Absorption of molybdenum by herbage may be increased to an undesirable extent where cobalt salts are applied in cobalt deficient areas.

Of the essential mineral elements, those required in comparatively large amounts are sodium, potassium, calcium, magnesium, iron, phosphorus, sulphur and chlorine, while copper, cobalt, manganese, zinc and iodine are necessary in such minute quantities as to be called " trace elements ".

One may, therefore, regard the ash of a feeding stuff as consisting of sulphates, chlorides, carbonates and phosphates of calcium, magnesium, sodium and potassium, with a good deal of silica and traces of the other elements mentioned.

In general, the mineral constituents are essential for the formation of bones, teeth, blood and other body fluids. They regulate the osmotic pressure and *p*H of these fluids. As previously mentioned, some of them, notably phosphorus and sulphur, enter into the composition of the soft tissues, while others help to control the rhythmic action of the heart and other muscles. They perform very important functions although comprising only about 3 per cent of the animal body. Certain elements may be conveniently described together in view of the fact that they function in conjunction with one another.

Calcium and phosphorus together comprise over 90 per cent of the ash of the animal body, about 99 per cent of the calcium and 80 per cent of the phosphorus being present in the bones and teeth. Here they provide hardening material and bones contain, in addition, protein (mainly ossein) and fat. Thus adult bones contain about half their weight of dry matter made up of approximately 52 per cent ash, 40 per cent protein and 8 per cent fat. Bone ash is mainly tricalcic phosphate (approximately 85 per cent), with a good deal of calcium carbonate (14 per cent), and a little magnesium phosphate (about 1 per cent). Calcium and phosphorus are present in the ratio 2 : 1 although slight variations may occur. There is still doubt concerning the exact nature of the compounds of calcium and phosphorus which exist in bones, but X-ray analysis has shown that they probably possess the apatite structure, e.g., hydroxy apatite $3Ca_3(PO_4)_2 \cdot Ca(OH)_2$ or carbonate apatite, $3Ca_3(PO_4)_2 \cdot CaCO_3$.

In addition to their function in bone formation, calcium salts are

essential for the clotting of blood, and phosphorus forms a constituent of nucleo-protein and blood. Because of their extensive presence in the animal body and also in animal products—milk contains approximately $\frac{1}{4}$ oz lime and $\frac{1}{3}$ oz of phosphate per gallon, expressed as CaO and P_2O_5 respectively—it is essential that animals receive abundant supplies of these elements. Good grassland herbage, especially leguminous herbage is an excellent source of both elements, but different types of pasture vary widely in mineral content (as they also do in nitrogen). This is well illustrated by the following figures giving the percentage of nitrogen, phosphoric acid and lime in the dry matter of five grades of pasture classified on the basis of the association of their plant constituents—

TABLE 2 (1)

Grade of Pasture	1	2	3	4	5
Nitrogen (N)	3·47	2·90	2·42	1·98	1·57
Phosphoric acid (P_2O_5)	0·94	0·76	0·59	0·44	0·26
Lime (CaO)	1·26	1·12	0·81	0·39	0·32

Certain feeding stuffs are very badly balanced in their content of calcium and phosphorus. Cereal grains are very poor in calcium but comparatively rich in phosphorus ; the reverse is true of roughages, and here again leguminous hay excels over ordinary meadow hay. Deficiency of these elements, or inability to use them adequately, leads to rickets and osteomalacia (see also vitamin D, p. 41).

The term rickets is usually applied to the characteristic malformation of the bones which occurs in young animals on a diet deficient in either or both of the above elements, or in vitamin D. Calcification of the bones is retarded, the bones become weak or brittle, and are pulled out of shape and sometimes fractured by the pull exerted upon them by the muscles. The misshapened condition is accentuated by the enlargement of the ends of the bones, and growth too is retarded. Rickets may be induced in rats on an adequate diet by the addition of substances which render the phosphorus unavailable. Ferrous sulphate, and compounds of aluminium, beryllium and manganese have been used in this way. In adult animals a similar weakening and malformation of the bones is called osteomalacia. The condition arises when the bodily demand for calcium and phosphorus exceeds the supply, and is most acute in the case of pregnant and lactating

[1] FAGAN, T. W., and DAVIES, R. O., 1937, "The nitrogen and mineral content of the produce of grassland," Report of the Fourth International Grassland Congress, Aberystwyth, Great Britain, p. 372

animals, which draw upon the calcium compounds of their bones in order to meet the needs of the growing foetus and of lactation.

Pigs and young calves are very susceptible to rickets, and the former may be seen searching among mortar and similar debris in an attempt to find supplies of minerals such as lime, which are often lacking in their diet of highly concentrated foods. More mature animals, especially when they receive inadequate supplies of green foods or other good sources of minerals, may exhibit a " depraved appetite," i.e., they chew stones, ashes, tins and even clothing, probably in an attempt to satisfy their craving for mineral substances. Lame sickness (Lamsiekte) amongst cattle in South Africa, is due indirectly to phosphorus deficiency, and is a condition of intoxication caused by a pathogenic saprophyte, *Clostridium botulinum*, which infests the bones and carcasses eagerly devoured by animals with perverted appetites in an attempt to make good their phosphorus deficiency.

Calcium deficiency also produces milk fever in dairy cows, a condition arising at the commencement of lactation following a sudden drop in blood calcium, and is characterised by tonic muscular spasms, paralysis and loss of consciousness leading to coma. Treatment consists in injecting calcium chloride, gluconate or other suitable calcium salts, usually in conjunction with magnesium salts, and often with spectacular results.

In addition to the actual amounts of calcium and phosphorus present in foods, the ratio of Ca : P is also of considerable importance, and the ratio of these elements in bones (2Ca : 1P or $1{\cdot}2CaO : 1P_2O_5$) appears to be desirable, although it may vary a good deal without harmful results unless calcium, phosphorus or vitamin D are deficient. A large excess of either element—for instance, phosphorus in a diet rich in cereals —will aggravate a deficiency of the other, whereas, if both are present in large amounts the ratio is of less significance. This is also true when both are in short supply, for harmful effects will appear whatever the ratio might be.

Magnesium.—The role of this element in animal nutrition is imperfectly understood. It is present in all herbage and widely distributed in the animal body, mainly in the skeleton. In action it is apparently closely associated with calcium and phosphorus, and disturbance of calcium metabolism appears to be one of the most pronounced features of magnesium deficiency, which may appear in calves on a diet low in magnesium causing pathological deposition of calcium in the soft tissues, and possibly interference with normal calcification of the bones. A sudden drop in blood magnesium produces lactation or grass tetany in dairy cows and also in other cattle and breeding ewes. Frequently, but not always, it occurs in dairy cattle within a week or two of turning out to

grass in the spring and is highly fatal. The symptoms resemble those of milk fever to some extent, but more acute excitability, tetany and convulsions characterise grass tetany. Treatment too is somewhat similar, and the condition responds promptly to injections of calcium and magnesium chlorides, magnesium sulphate or calcium gluconate. Low blood magnesium is sometimes accompanied by low calcium.

Magnesium also activates the enzyme phosphatase and plays a part in carbohydrate metabolism and in the formation of teeth.

Sodium and potassium.—Compounds of these elements occur in all parts of the body, mainly in the soft tissues and in the blood. Sodium forms more than nine-tenths of the total bases present in blood serum, and sodium chloride is also essential for the secretion of gastric juice containing HCl. Because perspiration contains a good deal of sodium compounds, animals and humans living in hot climates require more than those in temperate zones. Foods of animal origin are better sources of sodium chloride than are vegetable foods, so that herbivores and vegetarians may suffer a deficiency. Vegetable foods are considerably richer in potassium than sodium, and animals are usually assured of abundant supplies. Compounds of potassium function in muscle metabolism, but their mode of action is not fully understood, and this also applies to the way in which they are distributed in the body. Thus compounds of potassium occur chiefly within the cells, while those of sodium are mainly present in the extracellular fluids. Furthermore, blood is far richer in sodium than in potassium compounds, whereas the reverse is true of milk.

Another animal product particularly rich in compounds of potassium is the suint present in wool, and unwashed wool contains as much as 5·6 per cent of K_2O.

Chlorine is important in combination with sodium and potassium. Chlorides comprise the greater part of the anions of blood, and are of fundamental importance as HCl in gastric juice. They occur abundantly in many vegetable and animal products, and animals receiving a mixed vegetable diet are not likely to lack adequate supplies. Cereal grains and their products may be cited as examples of foods poor in chlorine.

Deficiency of sodium chloride is probably the most common mineral deficiency in animals confined to a vegetable diet, and causes retarded growth and reduced ability to utilise digested carbohydrate and protein. Poultry and pigs consuming kitchen waste may suffer from an excess of common salt, which causes oedema due to abnormal retention of water.

Sulphur functions mainly as a constituent of the amino-acids cystine and methionine ; it also occurs in small amounts in blood in the form of sulphates, in saliva as thiocyanate, and in the hormone insulin.

It is of great importance in the formation of wool, which contains approximately 4 per cent of sulphur. The element occurs in the form of the amino-acid cystine present in wool to the extent of about 13 per cent, although most proteins contain not more than 1-3 per cent. Goose feathers also contain about 3 per cent of sulphur.

Iron and copper.—These two elements occur in small amounts in the animal body, copper in traces only and iron as a constituent of haemoglobin. Iron also acts as a catalyst in cellular oxidation. Copper occurs in blood and liver, and is essential for the formation of haemoglobin although not a constituent of this substance.

Plants too are relatively poor in iron, but deficiency is not common. Pulse crops, cereals, greens, meat and eggs are good sources, but milk is deficient, and may induce anaemia in children and young animals kept on a milk diet after their reserves of iron have been exhausted. Colostrum, the fluid secreted by the cow after parturition, contains about 17 times as much iron as normal milk. Sow's milk is deficient in iron, and to avoid anaemia piglets reared indoors are given access to turves, or provided with iron in the form of a solution of cane syrup containing a little ferrous sulphate and also copper sulphate. Deficiency is most likely to occur just prior to weaning and before the piglets receive trough food (Chapter 20).

Deficiency of copper is not an uncommon occurrence, and is found in many counties of England, Wales and Scotland, where it gives rise to a condition known as " Swayback " in lambs, which, in the absence of treatment, is almost 100 per cent lethal and consequently does not manifest itself in adult animals. Affected lambs find difficulty in rising from the recumbent positon : if successful the hindquarters sway, are dragged along and the lamb may stagger and collapse. Copper sulphate, in mineral mixtures given to pregnant ewes at the rate of 10 mg copper salt daily, is an effective control measure, and the lambs are born normal.

Milk is deficient in copper and it is significant that newly-born animals probably contain sufficient to carry them over the suckling period, for it has been shown that the liver of an unborn calf contained eight times as much copper as that of an adult animal. Copper also appears to play a part in the pigmentation of hair and skin, and occurs in the form of copper-protein compounds, haemocuprein in blood and hepatocuprein in the liver of mammals. Several oxidase enzymes are copper-protein compounds, so that copper plays a fundamental catalytic role in cellular oxidation-reduction reactions.

Cobalt, like copper, is a " trace " element, present in herbage in minute amounts only. Deficiency causes " pining " in sheep in many areas in England, Wales and Scotland, a condition characterised by loss of appetite, general listlessness, dry wool and eventually a dwindling to mere

skin and bone. Supplementing the diet, either by dressing the pastures with cobalt salts or incorporating them in licks, is beneficial.

"Bush sickness" and "Pines" in New Zealand and Australia, formerly attributed to iron deficiency, are now known to be due to deficiency of cobalt which possibly influences the metabolism of iron. Affected animals suffer from acute anaemia which results in pronounced emaciation. Small amounts of cobalt salts are an effective preventative and cure. Cattle are also affected by deficiency of cobalt.

Recent work has shown that the anti-pernicious anaemia factor obtained from liver contains an atom of cobalt in its molecule.

Manganese is widely distributed in plants, especially in the outer coatings of seeds, and adequate supplies are essential in order to prevent the occurrence of leaf-stripe disease of oats. In animal nutrition it appears to function in the processes of reproduction, lactation and growth. Under experimental conditions rats and mice on diets deficient in manganese were adversely affected. In the male, degeneration of testicular tissues led to complete sterility. The females produced young but were unable to suckle them. It has also been shown that perosis or "slipped tendon" in chicks is related to manganese deficiency. The slipping of the tendon follows enlargement of the tibial-meta-tarsal joint and twisting of these bones. In severe cases the chick may die because it is unable to get about in search of food, but the trouble may be alleviated and prevented by administering the bran of cereals. It is aggravated by an excess of calcium or phosphorus, which apparently renders the manganese less available. Conversely, elements which convert phosphates into an insoluble form, e.g., iron and aluminium, have the reverse effect.

Zinc too appears to be distributed widely in vegetables in very minute quantities. Milk contains about 3 mg per litre and colostrum contains approximately three times as much. It occurs in most animal tissues, and deficiency has been associated with retarded growth and poor fur development in rats. Farm animals do not appear to suffer from a deficiency of zinc. Carbonic anhydrase, an enzyme present in red blood corpuscles, appears to be a zinc-protein compound which accelerates the dissociation of carbonic acid. All crystalline preparations of insulin contain zinc.

Iodine is present in small amounts in all green foods and in minute amounts in the animal body, mainly in the thyroid gland. This gland situated at the upper end of the trachea, secretes the hormone thyroxine, which is an amino-acid containing iodine. Deficiency of thyroxine retards mental, physical and sexual development, and in human beings is most prevalent during pregnancy and puberty.

When iodine is deficient, enlargement of the thyroid gland may occur in an attempt to supply more thyroxine. In farm animals the symptoms

usually appear in the young at birth, and calves may be born dead or in a very weak condition. Hairlessness is the outstanding symptom in pigs, and in foals extreme weakness and inability to stand.

Although it is well known that goitre is associated with certain areas, it appears that lack of iodine is not the sole cause, for the disease also occurs in areas where there is no deficiency of iodine in the water, soil and herbage. In such areas goitre is probably due to some factors which interfere with iodine metabolism. Where deficiency exists, iodised foods and licks afford useful supplements to the diet.

It will be evident from the above discussion that considerable information is now available concerning the effects of excesses and deficiencies of trace elements. There is, nevertheless, much uncertainty regarding the precise nature and causes of these troubles. Thus, " coast disease " and " salt sick," wasting diseases affecting grazing animals in Australia and Florida respectively, appear to be due to a dual deficiency of copper and cobalt. Swayback, apparently due to copper deficiency, may prevail on herbage showing no deficiency of this element, and it has been suggested that a high ratio of calcium to phosphorus, or a high content of lead or zinc, may affect the availability of the copper. Again, perosis in poultry is not due simply to manganese deficiency, but also appears to be related to the presence of choline. It has already been indicated too that goitre is not due solely to iodine deficiency, and that the scouring due to excess molybdenum may be prevented and cured by doses of copper sulphate, whereas cobalt salts increase absorption of molybdenum by herbage. Finally, one may point out that many diseases, some possibly identical in nature, are attributed to deficiency of a given element, e.g., pining in Great Britain, bush sickness and Morton Mains disease in New Zealand and enzootic marasmus in Australia, all apparently due to cobalt deficiency.

Mineral supplements or " licks "

It has been pointed out that foods of vegetable origin may give rise to a deficiency of common salt ; also, that cereal grains are poor in lime, and roughages in phosphate. In practice, most attention is paid to these minerals, deficiency of which is more prone to occur in some circumstances than in others. Young animals making very rapid growth require abundant supplies of lime and phosphate ; a young calf putting on about $1\frac{1}{2}$lb live-weight daily requires approximately an ounce of lime and phosphate in its daily ration.

Milk contains on an average approximately $\frac{1}{6}$oz of chlorine (Cl), $\frac{1}{4}$oz of lime (CaO) and $\frac{1}{3}$oz of phosphate (P_2O_5) per gallon, so that heavy milk yielders similarly require generous supplies of foods rich in these constituents. Pregnant animals also have high mineral requirements.

The practice of feeding large amounts of concentrated foods for milk production and to pigs may give rise to mineral deficiencies, for such foods are generally poor in lime and chloride, and, as pointed out above, animals receiving inadequate supplies may exhibit "depraved appetite."

Hill pastures are poor in lime and phosphate, and the breeds of sheep which thrive on the uplands are small-boned and have lower mineral requirements than the larger lowland animals. Finally, deficiencies of trace elements arise in certain areas where the rocks and soil are devoid of or poor in their compounds.

The existence of mineral deficiencies has long been recognised in farm practice and "supplements" of various kinds used. It was not uncommon to see lumps of rock-salt placed in positions accessible to cattle, whereas, from time to time, complicated "licks" have been employed containing such materials as bone flour, fish meal, ground chalk, common salt, iron oxide, potassium chloride, potassium iodide, magnesium sulphate, sodium sulphate, and charcoal.

It is probably best to use simple mixtures whose nature and contents are varied to meet the particular demands which may arise. Thus, deficiency of calcium and phosphorus in rations for pigs may be met by using a mixture containing two parts each of steamed bone flour and precipitated or finely ground chalk, and one part of common salt to increase palatability. Where calcium alone is deficient, the bone flour may be omitted. The proportion of salt may be increased if desired so that it comprises about 50 per cent of the total supplement in the case of cattle. The supplements are used by mixing 3lb with about 1cwt of concentrated food or meal, or provided in separate troughs.

In cases of special deficiency diseases, e.g., goitre, potassium iodide in the ratio of 1 part to 500 parts of the mixture may be used. Similarly, where swayback and pining occur, the conditions are improved by incorporating small amounts of copper and cobalt salts in the mineral supplements.

CHAPTER 5

THE VITAMINS

It has already been indicated that the bulk of a food is made up of moisture and the organic constituents, proteins, fats and carbohydrates with smaller amounts of mineral or ash ingredients. It is now known that, in addition, foods contain minute amounts of organic compounds essential for good health and normal growth, called vitamins. The discovery of definite principles and substances has frequently been preceded by knowledge—often quite extensive—of facts and phenomena later recognised to be intimately connected with them. The discovery of accessory food factors—later called vitamins—by Sir Frederick Gowland Hopkins, is a classic example of this, and certain diseases due to lack of vitamins, have been known, together with the appropriate remedies, centuries before these substances were discovered.

A condition akin to nightblindness, now recognised as being due to deficiency of a particular vitamin, was known to the Chinese many centuries ago, and substances having curative properties were used by them. Beri-beri, another vitamin-deficiency disease, was also known in China from early times, and scurvy has been known ever since long voyages of discovery were undertaken ; its cure by drinking the juices of citrus fruits is attributed to the British surgeon Lind (1747) who actually revived a discovery made by Sir Richard Hawkins in 1593.

An important observation was made in 1897 by Eijkmann who, as medical officer of a Java prison, was investigating beri-beri, a disease of the nervous system which appeared when natives forsook a diet of crudely milled rice for polished rice. He noticed that poultry also suffered from the disease when fed on such food left by ailing prisoners, instead of a mixed diet, which suggested that beri-beri was induced by something removed from rice in the " polishings." In 1911 Funk prepared a concentrated alcoholic extract of the " polishings," and found that a small dose cured avian beri-beri. He applied the term " vitamine " to this extract because he thought that it might be an amine. Despite the fact that this has long been disproved, the term vitamin is still retained.

Meanwhile, between 1906 and 1912, Sir Frederick Gowland Hopkins had carried out nutritional experiments with rats in which he showed the inadequacy of a diet consisting of carefully purified proteins, fats, carbohydrates and inorganic salts, for normal growth. Two groups of rats were fed on this diet, one group receiving in addition about 3 ml of milk, hardly enough to " nourish the tips of their tails." Although both groups

ate equally well, the rats receiving no milk failed to put on weight, whereas the others grew normally, the position being reversed when the diets were interchanged on the 18th day, showing that the result was due to some fundamental difference in the diets, not to unobserved differences in the two groups of rats. It was thus established that the milk provided some essential materials absent in the milk-free diet, and to these the name " accessory food factors " was given. These substances, now called vitamins, have been isolated from foods in a state of purity, their constitution established and in some cases syntheses accomplished, their number being added to from time to time.

The first to be recognised was vitamin A, and its discovery was later followed by the separation of vitamins into two groups, the fat-soluble vitamins A, D and E, and the water-soluble B and C. The former occur in association with fats and oils, fish liver oils being rich sources of vitamins A and D, whereas the latter, as the name implies, are soluble in water.

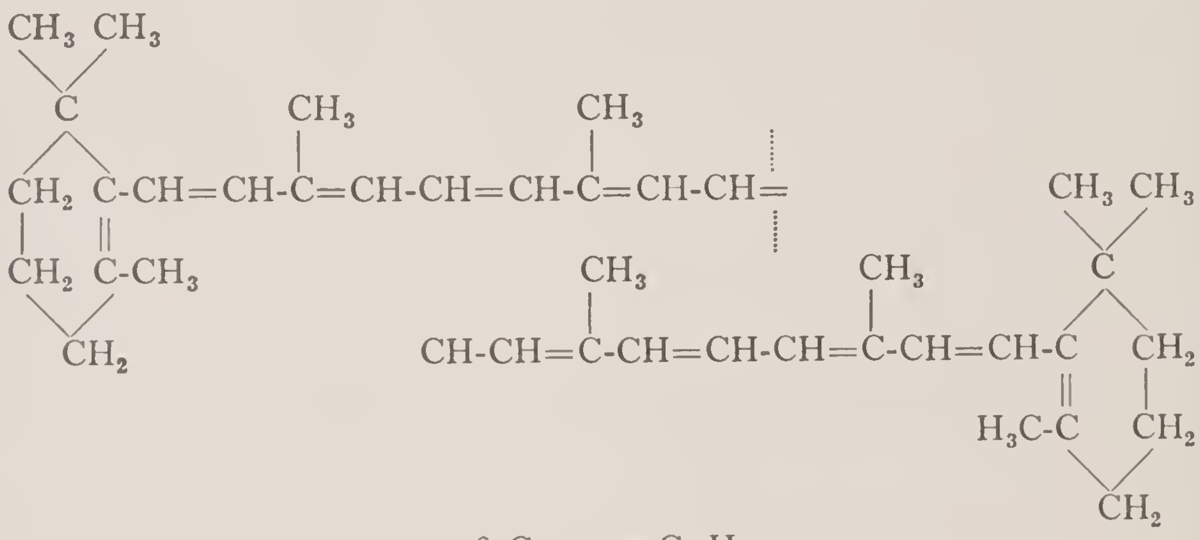
The fat-soluble vitamins

Vitamin A, Axerophtholl.—The liver oils of the halibut and cod are excellent sources of this vitamin, where it occurs together with vitamin D, whereas ox, sheep and pig livers, also good sources of A, are almost devoid of D. The amounts present in colostrum, milk, liver and egg yolk depend on the supplies present in the animals' food. Green vegetables are excellent sources of vitamin A although they do not contain the actual vitamin (see below).

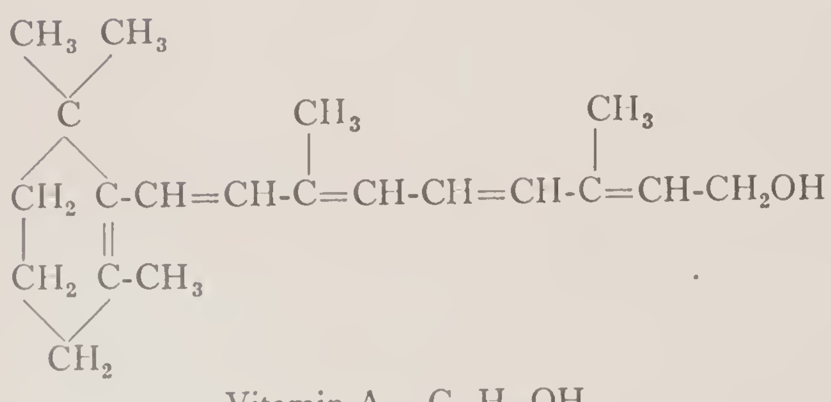
Vitamin A is essential for healthy, vigorous, normal growth and increases the body's resistance to disease. Where deficiency is acute, an inflammatory condition of the cornea and conjunctiva of the eyes, known as xerophthalmia, may develop. It has been induced in rats under experimental conditions, and may appear in poultry and cattle. The condition is common in children living under conditions of poverty, and also occurs in calves. Less acute deficiency may manifest itself in the form of " night blindness " in humans and cattle due to injury to the retina. This is probably due to the fact that vitamin A is used to synthesise rhodopsin or visual purple, a chromoprotein which enables the eye to adapt itself to dim light, and night blindness is most apparent in twilight.

A lowering of the animal's resistance to disease, as manifest in infections of the respiratory, alimentary and genito-urinary tracts, is a more general symptom of vitamin A deficiency, and is caused by a keratinising or " hardening " of their protective epithelial linings, rendering them more susceptible to bacterial penetration.

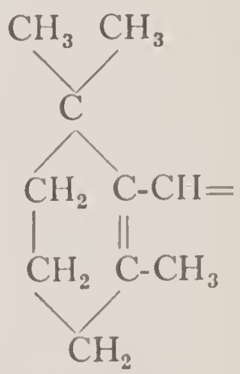
Elucidation of the chemical nature of the vitamin arose from a recognised association between the vitamin A potency of plants and depth of colour, particularly the yellow colour due to carotene. Actually carotene, $C_{40}H_{56}$, exists in three isomeric forms, α-, β- and γ-carotenes, and also as hydroxy-β-carotene or cryptoxanthin, all capable of transformation into vitamin A and called pro-vitamins. Only those carotenoids which contain the β-ionone ring can be converted into vitamin A. In β-carotene there are two β-ionone rings joined by a long chain of carbon atoms and the molecule is symmetrical, whereas α- and γ-carotenes possess only one of these rings. The conversion of β-carotene into vitamin A is effected in the liver, and was thought to involve a splitting of the molecule into identical halves which were oxidised to the corresponding alcohol. The actual mechanism is obscure and probably complex, and the potency of β-carotene is much lower than one would expect from the following formulae.



β–Carotene $C_{40}H_{56}$



Vitamin A $C_{20}H_{29}OH$



β–ionone ring

The unsaturation of these compounds renders them easily destroyed by both oxidation and reduction : the bleaching of the colour of dried green herbage exposed to air and sunlight, the instability of the vitamin A of

cod-liver oil under similar conditions, and its destruction in the process of catalytic hydrogenation during the manufacture of margarine, are examples of this. On the contrary, the interior of a mass of tightly packed baled dried grass and grass meal maintains its colour over prolonged periods, and cod-liver oil in tightly-sealed tinted bottles similarly retains its potency.

It is easily seen, therefore, that hay which has been exposed to the elements for considerable periods is almost devoid of carotene, and this is also true of hay heated in the stack, whereas grass dried artificially in 20-30 minutes is a comparatively rich source, although it may lose about 33 per cent of its carotene. Well-made silage, of a yellow-green or olive-green colour, also contains appreciable amounts of carotene, and in this respect excels over roots which, with the exception of carrots—a very rich source—are almost devoid of it. Fortunately animals are able to store vitamin A in their livers and are not immediately affected by a deficiency, which may occur during indoor feeding if green foods are not available. The colour of the body fat of cattle is mainly due to carotene, and both the fat and milk of Channel Island breeds contain more than the fat and milk of other breeds. The colour of milk fat and butter is a good indication of their carotene content, but it should be remembered that a variable amount of colourless vitamin A is also present. Colostrum is 5-10 times richer in carotene and vitamin A than normal milk.

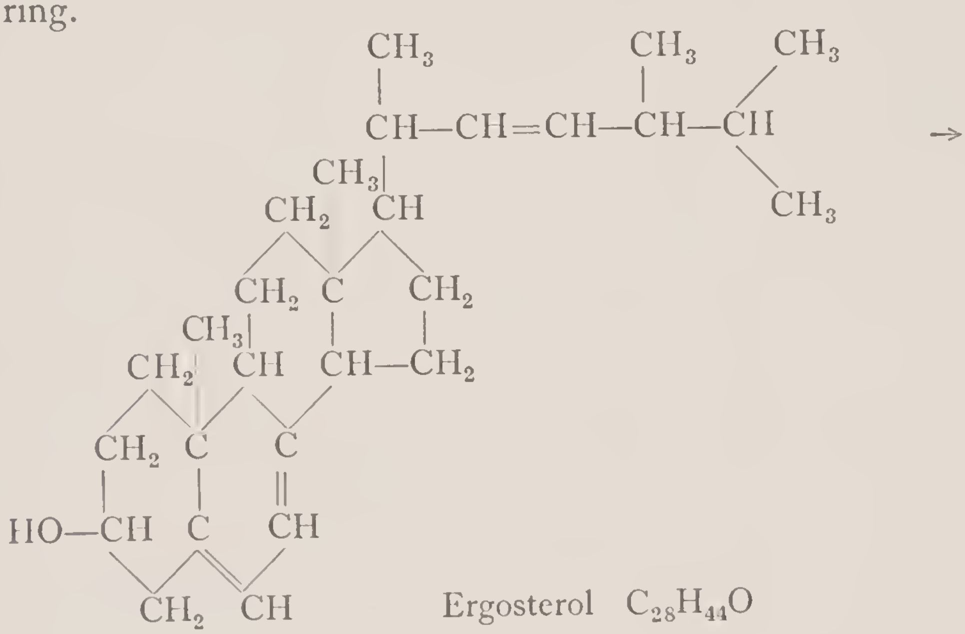
Vitamin D, Calciferol, the so-called anti-rachitic vitamin has the most limited distribution of all. Furthermore, animals appear to have a rather limited capacity for storing this vitamin, whereas they are able to store considerable amounts of vitamins A, C and E, and ruminants are able to synthesise members of the B complex. Animal products are generally poor sources, except in a few instances such as fish-liver oils and egg yolk. Milk is subject to great variation in vitamin D potency, being as much as ten times richer in the summer than in winter ; on an average it does not contain sufficient to prevent rickets.

Vegetable foods generally contain little, if any vitamin D, although crops such as hay may acquire small amounts after cutting and exposure to the sun. Cacao-shell meal, a sun-dried product, is a remarkably rich source, but must be used in restricted amounts because it also contains theobromine, a toxic substance.

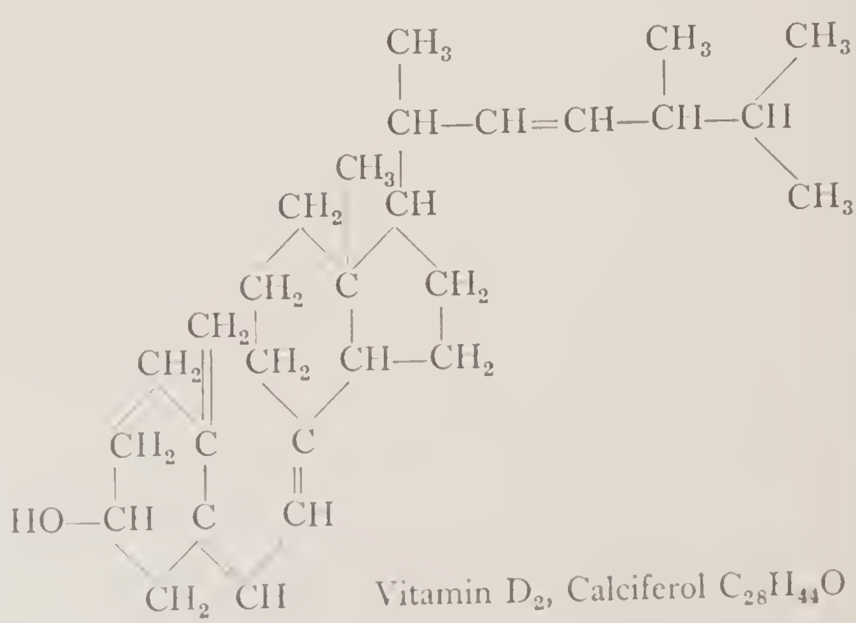
Rickets has long been associated with lack of sunshine and also cured by means of cod-liver oil which, together with the liver oil of the halibut and particularly the tunny, is rich in vitamin D. More recently it has been shown that not only may rickets be cured by sun-treatment, but that the disease does not appear in animals exposed to sunlight even when fed on diets deficient in the vitamin ; moreover, exposure of the food to sun-

light also suffices. It is now known that ultra-violet rays convert a natural constituent of foods, ergosterol, into vitamin D, the first vitamin to be identified. The name calciferol is derived from the role played by the vitamin in enabling animals to construct bones from assimilated calcium and phosphorus. In its absence they are unable to use these materials adequately ; the bones are ill-formed and soft and give rise to rickets in the young and osteomalacia—painful softening and deformation of the joints—in adult animals. The remarkable potency of the vitamin is illustrated by the fact that one part of it is estimated to enable the deposition of 3 million parts of calcium phosphate.

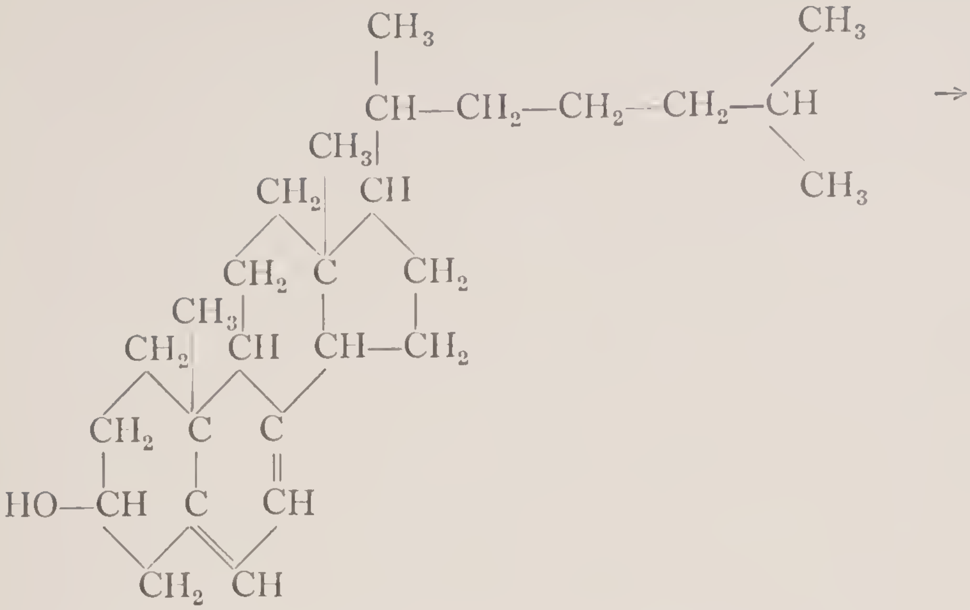
A number of anti-rachitic compounds are known, and the following formulae illustrate the nature of those formed from ergosterol and 7-dehydrocholesterol, the effect of irradiation apparently being to open a ring.



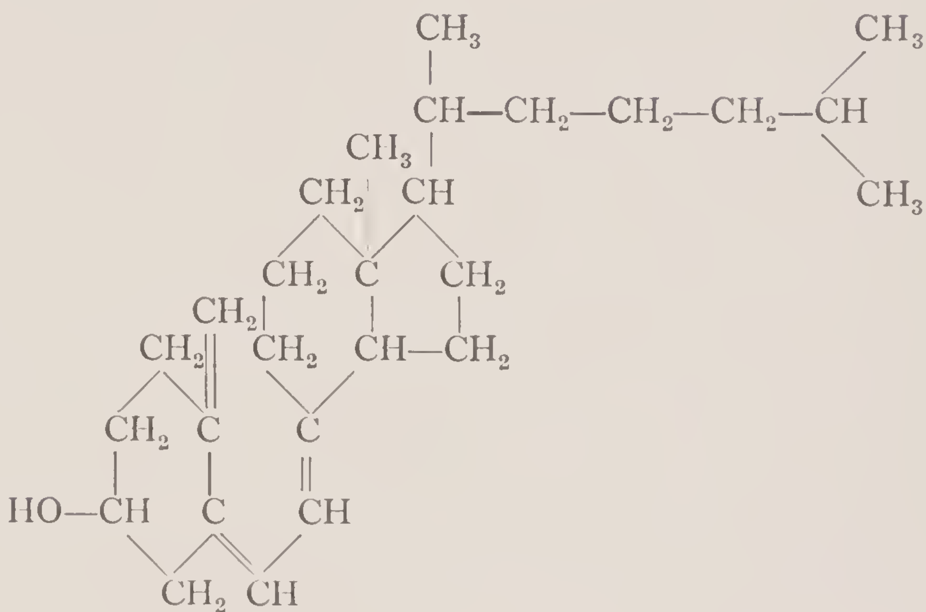
Ergosterol $C_{28}H_{44}O$



Vitamin D_2, Calciferol $C_{28}H_{44}O$



7-dehydrocholesterol $C_{27}H_{44}O$



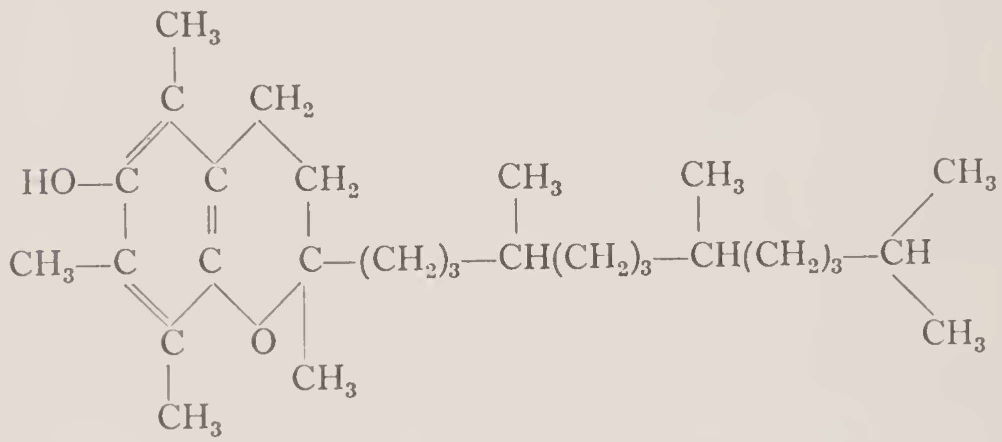
Vitamin D_3 $C_{27}H_{44}O$

It has been shown that the vitamin D present in many liver oils is more effective in chick dietaries than calciferol, and appears to be identical with vitamin D_3 produced by irradiating 7-dehydrocholesterol. It is probable, therefore, that vitamin D_3 and its precursor in the animal body are derivatives of cholesterol rather than ergosterol. As shown above these vitamins differ very slightly in constitution, calciferol containing a double bond in the side chain and one more CH_3 group.

Unlike vitamin A, these vitamins are much more resistant to oxidation, a fact which is obvious from the mode of formation in sun-cured herbage. An abundance is ensured when farm animals have free access to sunlight in summer and sun-dried roughages in winter. Cod-liver oil is often administered to supplement the diet of children, calves and poultry ; vitamin A is, of course, supplied at the same time.

Vitamin E, Tocopherol is also known as the anti-sterility vitamin as it is essential for reproduction, at least in rats and poultry. It is abundant in cereal grains and other seeds, especially in the germ oil, and in such greens as spinach, lettuce and water cress, and most farm foods contain a certain amount. It is also present in such animal products as egg yolk, and in rather limited amounts in milk. Oils rich in this vitamin are generally poor sources of vitamins A and D.

Vitamin E is stable to heat and is not readily affected by exposure to light or air, but is destroyed in foods which become rancid due to oxidation of fats and oils. It has been synthesised and has the following constitution—



Vitamin E, α–Tocopherol, $C_{29}H_{50}O_2$

In spite of this, however, less is known about the biological significance of this vitamin than of the others. Tocopherol exists in α-, β-, and γ-forms, and several related substances have a similar activity. It is unlikely that farm animals should suffer deficiency of vitamin E under normal conditions. Under conditions of low vitamin supply, sterility may arise from deficiency of either or both vitamins A or E.

The water-soluble vitamins

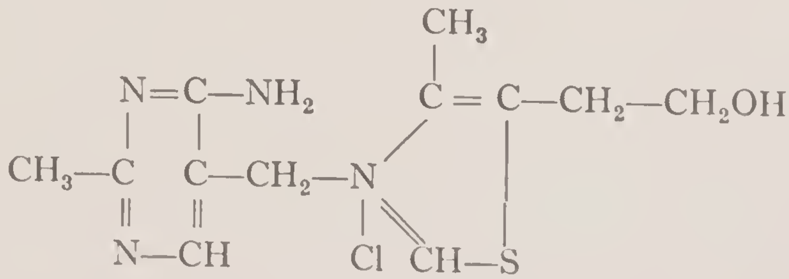
The Vitamin B complex.—There has been considerable confusion concerning this group of substances. Whereas it was originally thought

that vitamin B was a single antineuritic substance, it is now known that there are several factors in what is called the "vitamin B complex," all having specific functions. In general, it may be said that these occur together in the outer coatings and embryo of seeds, in yeast and its products, and in greens, fruit and milk. Because of their wide distribution in plant products, it is unlikely that farm animals should suffer from any deficiency of "vitamin B," and this is particularly true of ruminants which are able to synthesise this group of substances.

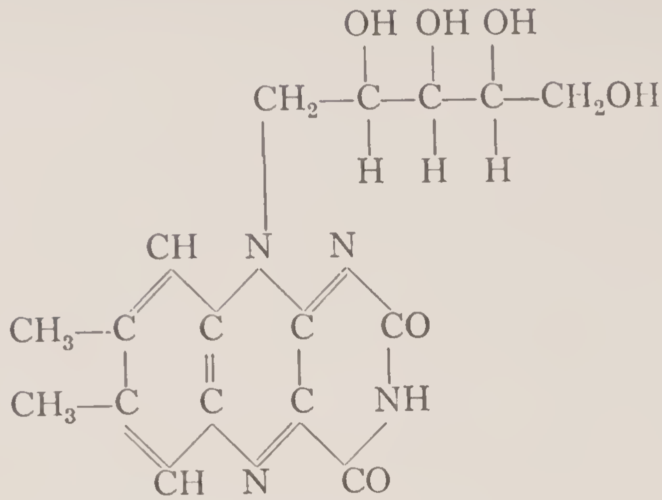
Many disorders are known to arise from deficiency of vitamin B, using the term in a wide sense. One of the most common is beri-beri, a nervous disease characterised by loss of appetite, fatigue, depression, numbness and a burning sensation in the limbs. It is widespread among the poor classes of Eastern peoples whose diet consists predominantly of polished rice, i.e., rice from which the outer coatings have been removed. An avian disorder, polyneuritis, is produced in the same way, the birds, for example, poultry, suffering from retraction of the head, convulsions and inability to stand properly. Both forms of the disease are easily cured by adding rice polishings to the diet.

Other associated deficiency diseases are pellagra and dermatitis. The former is found among the maize-eating peoples of central Europe and the southern United States, and among the symptoms associated with pellagra are acute dermatitis, ulceration of the mouth and tongue, diarrhoea and digestive disorders partly due to failure of the gastric secretion of HCl, and melancholia leading to insanity.

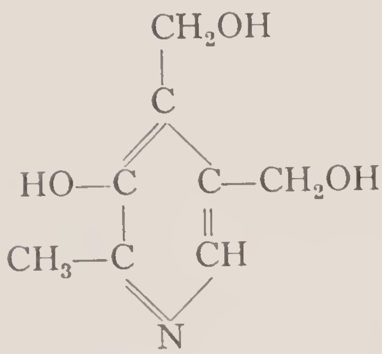
The following substances are among those found in the vitamin B complex; aneurin or thiamin (B_1), deficiency of which causes beri-beri, riboflavin or lactoflavin (B_2) a growth-promoting factor, nicotinic acid which prevents pellagra in man and black tongue in dogs, pyridoxin (B_6) the rat anti-dermatitis factor, pantothenic acid the chick anti-dermatitis factor, and choline which, together with manganese deficiency, is associated with perosis in poultry (p. 35). They have the following formulae—



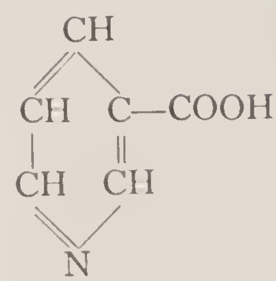
Vitamin B_1, Aneurin (Thiamin) $C_{12}H_{17}ON_4SCl$



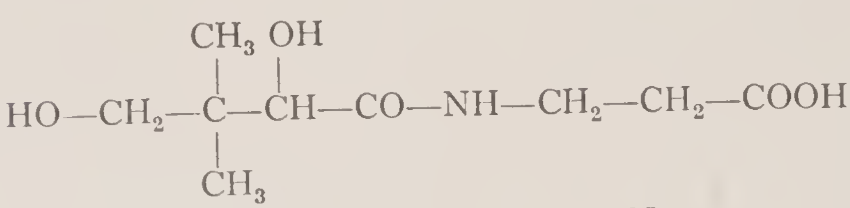
Vitamin B_2 or G, Riboflavin $C_{17}H_{20}O_6N_4$



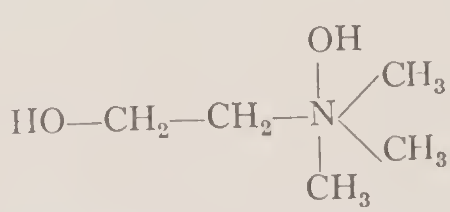
Vitamin B_6, Pyridoxin (Adermin) $C_8H_{11}O_3N$



Vitamin B_7
Nicotinic acid
(Niacin)$C_6H_5O_2N$



Pantothenic acid $C_9H_{17}O_5N$



Choline $C_5H_{15}O_2N$

Occurence and general functions of the vitamins of the B-complex.— These compounds are widely distributed in foods. Although some foods such as yeast and cereals are good sources of several members, certain foods may be poor in a given B vitamin. Thus cereals are good sources of aneurin and nicotinic acid but are poor in riboflavin. The latter is, however,

abundant in dairy products which are poor sources of aneurin. Liver, kidneys and glandular organs generally are good sources of both aneurin and riboflavin.

The distribution of some members in a given source is rather striking. Egg white contains little or no aneurin but is a very rich source of riboflavin, whereas egg yolk is a rich source of both compounds. Aneurin tends to accumulate in the germ of cereals, whereas nicotinic acid is present mainly in the bran. Pyridoxin and pantothenic acid too occur in small amounts in foods generally.

In addition to their related source, some, at least, of these vitamins are related in function, for they combine with phosphate to form co-enzymes, and these, in turn, combine with protein to form enzymes mainly concerned with cellular oxidation. In the form of its pyrophosphate ester, aneurin is the co-enzyme of carboxylase, an enzyme involved in carbohydrate metabolism. Absence or deficiency of aneurin prevents complete oxidation of glucose, and in consequence pyruvic acid ($CH_3CO{\cdot}COOH$) appears in the blood, e.g., in that of patients afflicted with beri-beri. Aneurin is also required for the conversion of carbohydrates into fat.

Many enzymes are known containing other members of the vitamin B complex. Warburg's "yellow enzyme" which catalyses cellular oxidations and reductions contains riboflavin, phosphoric acid and a protein.

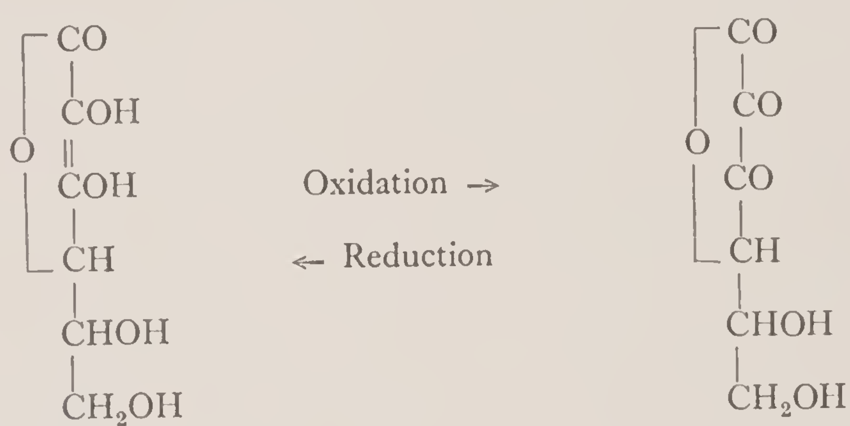
Vitamin C, the antiscorbutic vitamin, is widely distributed in plant products, but animal products including milk are poor sources. The juices of citrus fruits have long been used as a cure for scurvy ; other valuable sources are tomatoes and green vegetables, e.g., lettuce, spinach, cabbage, parsley ; also potatoes, turnips and swedes, and certain peppers. While absent in cereal grains, it is produced during germination, and appears to bear an intimate relationship with cell vitality generally. It is very easily destroyed by heating in air, especially in alkaline solution, and this is why cabbage and spinach are cooked preferably without the addition of soda. By carefully excluding air, many fruits and vegetables are preserved without serious loss of vitamin C, e.g., canned tomatoes, and tomato and black-currant juices. The rather small amount present in milk may be lost in passing over the cooler, and during heat-treatment serious losses occur. During pasteurisation losses may on an average amount to about 20 per cent, the corresponding losses for drying and condensing being respectively up to 30 and 60 per cent. It is interesting to note that the losses suffered by other vitamins during similar treatment are comparatively slight, except in the case of vitamin B_1 where losses of 10-40 per cent occur.[1]

[1]Kon, S. K., 1941, "Relative nutritive value of different forms of milk," *Nature*, Lond., **148**, p 607.

Acute scurvy is now rare in European countries, but was common among sailors in the days of the sailing ship when the length of the voyages made access to fresh foods difficult. Following the issue of 1 oz of lemon juice daily to every sailor in 1795 this scourge was eliminated from our Navy. The advanced form of scurvy is accompanied by general haemorrhage due to a weakening of the walls of the capillaries. Bleeding of the nose and gums, loosening of the teeth and painful swelling of the joints are typical symptoms, which may be accompanied by nervous symptoms and a low resistance to infection.

It appears that rats, dogs and birds are able to synthesise vitamin C from some other substance, whereas men, monkeys and guinea-pigs are unable to do so, and must obtain a supply in their food. Farm animals are apparently in little need of the vitamin and unlikely to suffer from a deficiency.

Vitamin C has been isolated, identified as ascorbic acid and synthesised. It is prepared from glucose on a commercial scale, and in constitution is closely related to a hexose sugar from which it is probably derived by oxidation.



Vitamin C, Ascorbic acid $C_6H_8O_6$ Dehydroascorbic acid $C_6H_6O_6$

Although no carboxyl group is present, the presence of the > CO group enables the H atom in the adjacent OH group to ionise, conferring feebly acid properties upon the molecule. Ascorbic acid readily undergoes reversible oxidation to dehydroascorbic acid, and in this way may function in cellular oxidation and reduction reactions.

Other vitamin factors

There are many vitamins in addition to those described above and new members are continually being discovered. They include vitamin K concerned with the clotting power of blood, vitamin H or biotin necessary for the normal growth of certain yeasts, moulds and bacteria, para-amino-

benzoic acid essential for the normal growth of chicks and the maintenance of normal fur in rats, inositol associated with normal growth of chicks, the growth of hair in mice and a " spectacled eye " condition in rats, folic acid which promotes growth and prevents anaemia in chicks, and other factors whose nature and functions are rather obscure. Little is known regarding their significance in the nutrition of farm animals.

Standards of vitamin potency

With advancing knowledge of the chemistry and physiology of the vitamins, and the isolation of individual members in a state of purity, it becomes necessary, from time to time, to draw up internationally accepted standards of vitamin potency. The amounts are stated in milligrams ($1 \text{mg} = 0{\cdot}001 \text{g}$) and micrograms ($1 \mu\text{g} = 0{\cdot}001 \text{mg}$), and the following examples represent one international unit (I.U.) of some of the more important vitamins: vitamin A, $0{\cdot}6 \mu\text{g}$ of β-carotene; vitamin B_1, $3 \mu\text{g}$ of pure anhydrous aneurin; vitamin C, 0·05 mg of *l*-ascorbic acid; vitamin D, $0{\cdot}025 \mu\text{g}$ of the pure vitamin; vitamin E, 1 mg of synthetic α-tocopherol acetate.

In conclusion, attention should be drawn to the fact that, although vitamins have specific functions, there is a certain amount of interrelationship of function; thus deficiency of vitamins A or E causes sterility, A, D and C influence bone formation although perhaps not in the same way, A, B_2, D and E have an effect on growth, and vitamin C as well as A appears to be associated with resistance to infection. Moreover, the original ideas concerning the nature and functions of vitamins have undergone considerable modification. It is obvious from their chemical structures that they do not constitute any one class of compounds, and from this point of view there is no justification for grouping them under one heading. The one feature which they have in common is their presence in foods in such minute amounts and their remarkable potency, comparable with that of the enzymes to be discussed in the next chapter. Many enzymes do, in fact, contain vitamins in their molecules.

CHAPTER 6

DIGESTION, ABSORPTION AND USE OF FOOD

Enzymes

THE chief aim of the earlier experiments on digestion was to dispel the idea that the stomach was a grinding mechanism. The methods used were ingenious and interesting. Reamur enclosed food in small perforated metal tubes which animals were forced to swallow and later to disgorge, whereupon it was found that meat and cheese were partially dissolved, whereas starchy foods were unattacked. In 1783 the Abbé Spallazani found that digestive juice was capable of dissolving fragments of meat. The juice was obtained by making a tame eagle swallow a sponge tied to a string and recovering it full of liquid.

Many natural processes were known to be brought about in a somewhat similar manner, to name only the fermentation of sugary liquids to make wines and the use of yeast in bread-making, but about fifty years elapsed after the above observations were made, before the more systematic study of organic chemistry brought a renewed interest in fermentation and enzymes, the name given to the active principles concerned.

Pasteur regarded alcoholic fermentation as a purely physiological action inseparably bound up with the life of the yeast cells, for he had shown that no changes occurred in sterile material. Liebig and Berzelius, on the other hand, held that fermentation was purely chemical in nature, and the controversy was not settled until Buchner in 1897 proved that juice expressed from yeast cells retained its activity in the absence of any intact living cells. He gave the name zymase (from a Greek word meaning yeast) to the enzyme present in this juice.

It is now generally agreed that all fermentative changes are brought about by enzymes, which may be defined as organic catalysts produced by living organisms. Enzymes are so named that they end in "ase," e.g., maltase hydrolyses maltose, and lipases hydrolyse certain lipides or fats. A few old established names are still retained, however, e.g., ptyalin and pepsin. Although the precise nature of enzyme action is not fully understood, several enzymes have been prepared in very high degrees of purity and obtained in crystalline form, e.g., urease, pepsin, trypsin and trypsinogen. Their properties and molecular weights show them to be proteins, but they probably differ in some respects from catalytically inactive proteins. Certain enzymes contain a vitamin as well as a protein in their molecules (p. 47).

For our present purpose it will suffice to outline briefly some of the more important properties of enzymes in general. One of the most striking is their remarkable potency, for minute amounts are able to carry out hydrolysis and other chemical changes. The enzyme invertase is capable of hydrolysing about one million times its own weight of sucrose, and certain preparations of amylopsin or amylase hydrolyse starch with similar activity. Moreover, such changes are effected under mild conditions, for example gentle warmth and mild acidity or alkalinity, whereas, in the absence of enzymes, they are accomplished in the laboratory only by using comparatively high temperatures and strongly acid or alkaline solutions.

Enzymes resemble catalysts in increasing the speed of reactions, and in catalysing forward and reverse reactions without influencing the direction of the change or the position of equilibrium. Maltase, for example, hydrolyses maltose and may condense two glucose units again, whilst pepsin can hydrolyse proteins and accomplish a partial synthesis as well. Maltase, however,—and similarly other enzymes—does not decide the direction of the change or the amounts of maltose and glucose present when, at a given temperature and concentration, equilibrium has been attained.

They are specific in action, and members of a particular group are able to catalyse only one type of reaction. Thus, lipases hydrolyse fats only ; carbohydrases and proteases, carbohydrates and proteins respectively. While in general one type of enzyme can hydrolyse many related compounds—e.g., lipase may hydrolyse many fats—in some cases a much greater specificity is apparent. The biological resolution of *dl*-ammonium tartrate by the mould *Penicillium glaucum*, observed by Pasteur, is a well-known example, the enzyme responsible attacking the *d*-isomer only, leaving the solution *l*-rotatory. In this instance, enzyme activity is controlled by the asymmetry of the molecule. Examples of this nature led Emil Fischer to compare the relationship between an enzyme and its substrate with that of a key and its lock, and it appears that some such relationship probably exists.

Another important property of enzymes is their sensitivity to heat and other conditions. The optimum temperature range for enzymes of animal origin is around 37–45°C. Above 45°C their action is still more rapid but, as they themselves are rapidly destroyed, the net result is usually a decrease in activity. Destruction is more rapid as the temperature rises, and is almost immediate at 100°C. Many are equally sensitive to acid and alkaline conditions. Pepsin attacks proteins only in acid media with an optimum range of acidity between *p*H 1·8–2·0 ; trypsin, on the contrary, requires mild alkalinity for optimum activity

(pH 8·0), whereas ptyalin acts best in the almost neutral saliva and apparently requires the presence of Cl ions. Substances whose presence is essential for the action of enzymes are called co-enzymes. Thus, alcoholic fermentation will not take place in the absence of phosphates, and bile salts are essential for the enzymic hydrolysis of fats in the small intestine.

Further, it appears that some enzymes are secreted in an inactive form or zymogen and need activating; this is true of trypsinogen, which attacks proteins only after activation by enterokinase, with which it probably forms a complex, the active enzyme being trypsin. Similarly, pepsinogen is converted into active pepsin by the hydrochloric acid of the gastric juice.

Finally, it may be noted that enzymes, like catalysts, are susceptible to poisoning, especially by compounds of silver, mercury and other heavy metals, as well as by cyanides, fluorides and alkaloids. The body itself may secrete inhibiting substances which protect the tissues against the proteolytic (protein splitting) action of enzymes, e.g., the stomach wall is protected by the secretion of antipepsin.

Digestion, absorption and use of food

The process of digestion includes all the processes which take place in the alimentary tract, from the mouth to the anus, and serves to prepare food for absorption and use in the body. A few compounds such as the mineral salts and monosaccharides, can pass into the blood stream without further change; the majority need to be split up into much simpler molecules before they penetrate the intestinal walls.

Digestive processes may be classified into two groups—

1. *Mechanical processes.*—These include chewing and mastication by the teeth, and muscular movements of the stomach and intestines which break up the mass of food and mix it with digestive juices. Muscular movements are especially important in the four-compartment stomach of ruminant animals, cattle, sheep and goats. The first three compartments, the rumen (by far the largest), reticulum, and omasum, function in this way and, acting also as storage organs, account for the large masses of fibrous food with which ruminants are able to cope. From these the food passes into the true or rennet stomach, the abomasum, after it has been regurgitated from the first two compartments and remasticated, and finally kneaded by leaf-like membranes in the omasum until fine enough to pass on.

Horses and pigs have simple stomachs, and pigs are able to deal with very limited amounts of fibrous foods. The horse, however, possesses a large intestine (comprising the caecum and colon) of much greater capacity

than the large intestine of other farm animals, and is able to utilise quite large quantities of bulky fodders.

2. *Chemical processes.*—With reference to the foregoing, it should be pointed out that the ability of ruminants to deal with bulky roughages is not entirely due to the fourfold nature of their stomachs, but also to the fact that bacteria in the first three compartments are able to digest cellulose and pentosans so abundant in this type of food. This is also accomplished in the caecum and colon of the horse and, to a lesser extent, in the large intestine of other animals. These bacteria break down cellulose and pentosans into carbon dioxide and methane, organic acids, chiefly acetic and butyric, and possibly into simple sugars which are then used as food. In this way other food constituents are set free from their fibrous covering and are exposed to the hydrolytic action of enzymes.

In the mouth food is thoroughly mixed with saliva. The amylase or ptyalin present converts starch into maltose, and this action continues until the bolus into which the food is formed is swallowed and permeated with the acid gastric juice of the stomach, which stops ptyalin action. Whereas human saliva contains ptyalin, there is little present in that of farm animals with the exception of the pig. This is an advantage, because any maltose produced by salivary digestion would suffer bacterial decomposition in the ruminant stomach, and be lost.

The stomach or gastric juice contains HCl, the amount varying with the species of animal from 0·1 to 0·5 per cent. The juice is secreted by the peptic glands of the stomach wall, and the enzymes present in the stomach act only under acid conditions. One of these, namely pepsin, effects a partial hydrolysis of protein to produce proteoses and peptones. Rennin, present in the stomachs of young animals, curdles milk and prevents it from passing into the small intestine before its proteins can be attacked by pepsin. In addition to producing the acidity essential for peptic action, the hydrochloric acid also prevents undesirable bacterial fermentations which would occur at a higher *p*H. It also hydrolyses some sugars, that is, it converts sucrose into glucose and fructose, and helps to set free the fatty food constituents from their more fibrous covering. A little fat may be hydrolysed by the warm HCl and by the action of lipase, which is very slight at the normal *p*H of gastric juice (1–2), for the optimum *p*H for gastric lipase is about 5.

When sufficiently digested the semi-fluid food or chyme passes slowly through the pyloric orifice into the small intestine. The rate of flow is controlled by a ring of muscles called the pylorus, and this action is in turn controlled by the acidity which develops as digestion proceeds. It is in the small intestine that the most active digestion occurs, for at this stage proteins and carbohydrates are only partially digested and fats are

little affected. The small intestine is about 130 ft long in mature cattle, 70 ft in horses, 80 ft in sheep, 60 ft in swine and 22 ft in man. It receives pancreatic juice from the pancreas, bile from the liver and intestinal juice secreted in the intestine itself. The mixture is alkaline due to the presence of sodium carbonate. The wave-like muscular contractions of the intestinal walls, known as peristalsis, cause the food to pass along, and after admixture with the above juices it becomes slightly alkaline.

Among the enzymes present in the small intestine are trypsin, " erepsin," amylase and lipase. It was thought that trypsin converted proteins into amino-acids, while erepsin attacked proteoses and peptones and hence completed the work of pepsin, but it has now been shown that pure trypsin is unable to hydrolyse proteins beyond the stage of proteoses or polypeptides ; further hydrolysis is completed by a number of peptidase enzymes including carboxypeptidase and aminopeptidase which act on polypeptides, and dipeptidase which hydrolyses dipeptides. The so-called erepsin is actually a mixture of enzymes. Conversion of starch into maltose is effected by amylopsin or amylase, and maltose and other disaccharides are further hydrolysed into monosaccharides by the appropriate enzymes.

$$C_{12}H_{22}O_{11} + H_2O = C_6H_{12}O_6 + C_6H_{12}O_6$$

Sucrase	converts	Sucrose into Glucose + Fructose
Maltase	,,	Maltose into Glucose + Glucose
Lactase	,,	Lactose into Glucose + Galactose

Fats and oils are hydrolysed into glycerol and fatty acids by a lipase called steapsin, whose action is greatly enhanced by the presence of bile salts, which lower the surface tension and help to emulsify the fat so that the globules come into more intimate contact with the enzyme. Bile salts also facilitate solution of the products by forming complexes with the fatty acids which are soluble in water and are absorbed, whereas the fatty acids themselves are insoluble.

The secretion of juices by the pancreas, liver and intestine is controlled in such a way as to prevent either a deficiency or an excess of essential compounds. When, for example, there is no digestive action in the small intestine, pancreatic secretion ceases or is at a minimum, and actually begins when the acid chyme from the stomach enters the intestine and stimulates the secretion of a hormone or " chemical messenger " secretin, which is carried in the blood stream and stimulates the pancreas into activity.

After passing through the stomach and small intestine, the food enters the large intestine where digestion continues. All food constituents capable of digestion have now been broken down into compounds suffi-

ciently simple to pass through the walls of the intestine. Thus proteins have been split up into amino-acids, fats and oils into glycerol and fatty acids, and the carbohydrates into monosaccharides. Absorption of these constituents occurs mainly in the small intestine, whose walls are lined with cone-like projections called villi, which provide a large surface for absorbing the products of digestion and have a somewhat sponge-like action. It is completed in the large intestine, and the undigested residue is voided at the anus as faeces.

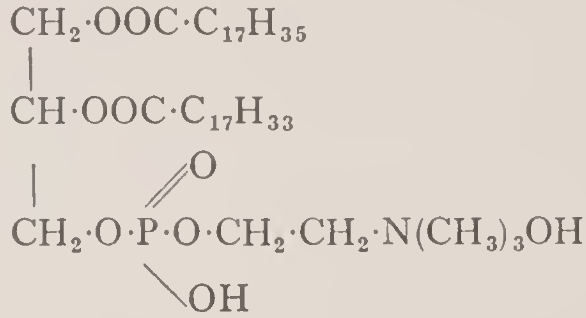
The products of digestion pass through the intestinal wall into the lymphatic vessels afterwards entering the blood stream, where they are used in a variety of ways. The monosaccharides, the end products of carbohydrate digestion, may be oxidised to supply energy for the maintenance of body temperature and for work. Glucose, present in excess of immediate energy requirements, is transferred to the liver where the enzyme glycogenase converts it into the reserve material glycogen, which appears to be formed with equal facility from fructose and galactose. It is a remarkable fact that, on hydrolysis, glycogen yields glucose only, showing that the body is able to convert one monosaccharide into another with much greater ease than is possible in the laboratory. Surplus sugars are also converted into fat and stored as adipose tissue surrounding the liver, kidneys and other organs, and in layers under the skin.

Although the mechanism of such changes is not fully understood, brilliant researches have shown that they are complicated and involve the formation of many intermediate substances. During the contraction of muscle, for example, glycogen is converted into lactic acid, but this simple statement is merely a summary of a series of chemical changes involving the conversion of hexoses into their phosphate esters. One of the most important is fructose diphosphate, which is converted in turn into dihydroxyacetone phosphate, phosphoglycerol and phosphoglyceric acid, phosphopyruvic acid, pyruvic acid and finally lactic acid.

The fate of the fats, also incompletely understood, is of similar complexity and will be dealt with in outline only. After absorption, the fatty acids are liberated from their bile-salt complexes and combine with glycerol to form fats, which are either stored or oxidised to afford a supply of energy. They appear to be broken down (and also synthesised) two carbon atoms at a time and, as previously mentioned, this would account for the fact that all naturally occurring fatty acids contain an even number of carbon atoms. The process known as β-oxidation probably involves a series of changes the end products of which are carbon dioxide and water. Because of the comparatively low proportion of oxygen present in fats, these substances are far more economical as sources of energy than are carbohydrates and proteins. In illustration of this, one gram of these

substances yields on combustion 9·5, 4·2 and 5·6 Calories respectively.

There is still doubt concerning the manner in which fats are transported in the blood stream, but it is probable that the closely related substances called phospholipides are involved. One of these, lecithin, is present in blood and also in milk ; it has the following composition—



It contains a glycerol residue combined to two fatty acid groups and also, through phosphoric acid, to the nitrogenous base choline ; on hydrolysis it yields these five substances. One fatty acid (stearic) is saturated, the other (oleic) unsaturated, and the close resemblance in structure to a fat is obvious (see also pp. 1 and 7).

The amino-acids produced in the digestion of proteins may also undergo resynthesis in various parts of the body to repair tissue waste and build up flesh, and tissues such as hair, wool, feathers, nails, hoof and horn. Along with fats and carbohydrates they are used in the production of eggs and milk. Amino-acids in excess of these requirements are used as sources of energy, after a process of deamination which involves elimination of nitrogen as ammonia, and oxidation of the acid to a keto-acid. These processes, probably enzymic in nature, occur throughout the tissues, but mainly in the liver, where the ammonia formed, after conversion into ammonium carbonate, is converted into urea and excreted via the kidneys in the urine. The deamination of alanine may be summarised as follows, the actual mechanism involved being rather more complex—

$$\underset{\text{Alanine}}{CH_3{\cdot}CH(NH_2){\cdot}COOH} + O = \underset{\text{Pyruvic acid}}{CH_3{\cdot}CO{\cdot}COOH} + NH_3$$

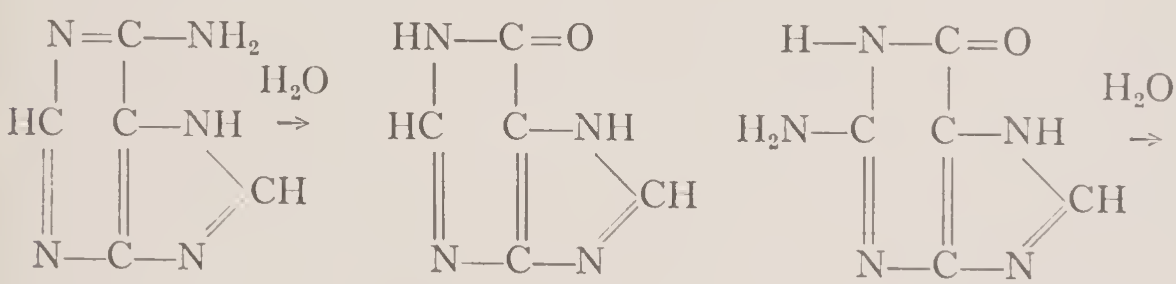
$$2NH_3 + H_2O + CO_2 = (NH_4)_2CO_3$$

$$(NH_4)_2CO_3 - 2H_2O = \underset{\text{Urea}}{CO(NH_2)_2}$$

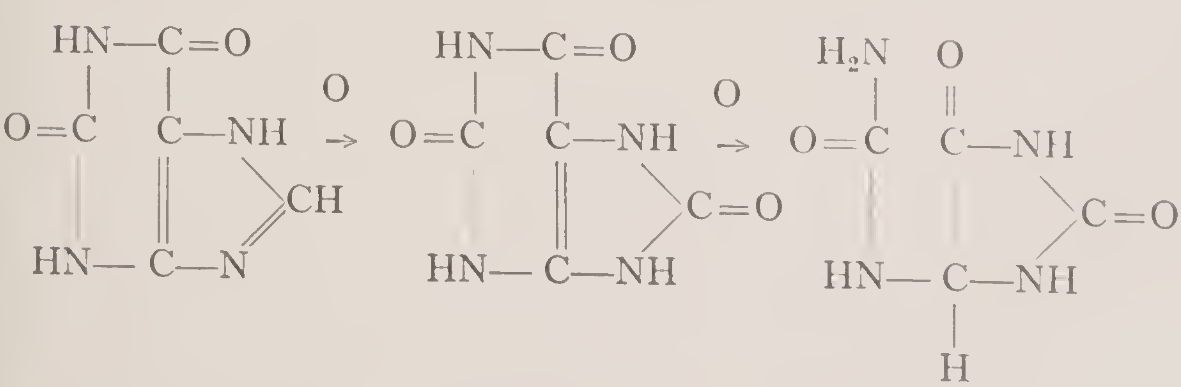
Simple keto-acids, such as that in the equation, are either oxidised to carbon dioxide and water or converted into glucose and hence into glycogen. They constitute important links between carbohydrate and protein metabolism.

In the foregoing description of digestion, the metabolism of proteins has been viewed from the standpoint of simple proteins only, and further reference should be made to the fate of some of the more important structures also present in conjugated proteins, which have been referred to in Chapter 3.

Nucleo-protein is broken down by pepsin into protein and nuclein, and the former hydrolysed into amino-acids as already described. The latter is broken down by the action of trypsin into protein and nucleic acid. Nucleic acid is hydrolysed by polynucleotidase present in the intestinal juice, which converts it into four nucleotides ; these are hydrolysed by nucleotidase to give nucleosides with the removal of phosphoric acid. The purine nucleosides are hydrolysed to sugar and purine bases by nucleosidase, and these products are then absorbed into the blood stream, whereas pyrimidine nucleosides are apparently absorbed unchanged. While little is known regarding the fate of pyrimidine bases, the purines adenine and guanine undergo a process of deamination and are converted by adenase and guanase into oxypurines ; adenine gives hypoxanthine and guanine gives xanthine which is also formed by further oxidation of hypoxanthine. Finally, xanthine is oxidised by xanthine oxidase to uric acid, the end point of purine metabolism in man, whereas in most mammals the enzyme uricase present in the liver carries the oxidation a step further producing allantoin—



Adenine Hypoxanthine Guanine



Xanthine Uric acid Allantoin

While uric acid is a sparingly water-soluble white crystalline solid, whose deposition in the joints of humans gives rise to the extremely painful and disfiguring conditions known as arthritis and gout, allantoin has the advantage of being much more soluble (actually about 250 times more soluble at 20°C). Purines derived from food are said to be exogenous in origin, while those derived from the breakdown of body tissues are said to be endogenous and undergo similar metabolism.

CHAPTER 7

THE DIGESTIBILITY OF FOOD

It is a well-known fact that certain human foods are more easily digested than others. Some, for example, milk and milk products such as junket, are chosen for invalid consumption because they are easily digested, while others are avoided because of the discomfiture caused after they are consumed. Such impressions relate to the ease or comfort of digestion, and often bear little relation to the proportion of the food ultimately digested. In the study of animal nutrition the word digestibility has a quite definite and limited meaning. It indicates the percentage of the dry matter (or other constituents of the food) that has been converted into compounds sufficiently simple in structure to be absorbed into the blood. A brief description of the method used to determine digestibility will serve to illustrate this conception.

Determination of digestibility

The actual digestibility of food constituents is determined by means of feeding experiments with animals, usually cattle or sheep. For this purpose the animals are housed in such a way that it is possible to weigh the total amount of food consumed and faeces voided. Since the faeces represent indigestible matter, it is essential that they should not come into contact with the urine, as this contains substances produced in the metabolism of digestible food constituents. The difficulty is overcome by using male animals equipped with harness which provides for the collection of dung in a bag. In view of the restrictions of movement imposed upon such experimental animals, and in order to get them accustomed to the food under investigation, the latter is fed for at least a week before any measurements are made.

The food fed daily is weighed and a representative sample taken for analysis. Any left unconsumed is, of course, weighed, and after weighing the solid excrement, this too is sampled and a convenient quantity retained for analysis. In this way it is possible to ascertain the total weight of food consumed over a period of about 14 days, and also the weight of solid excreted. Further, as a result of analysis, the total amounts of dry matter, crude protein and other food constituents consumed can be calculated, and, similarly, the total amounts excreted in the faeces. The difference between these amounts gives the weights of dry matter and individual constituents digested, and these are expressed as a percentage of the total consumed.

Two or three animals, as like as possible in weight and general features are chosen, and the data for each animal taken separately. An example will serve to illustrate the type of data obtained in an experiment of this kind, the object of which was to determine the digestibility of grass silage.

A sheep consumed on an average 2,900 g silage per day containing 22·8 per cent of dry matter.

The weight of dry matter consumed was $2{,}900 \times 22{\cdot}8/100 = 661{\cdot}2$ g. Similarly, the average weight of dry matter excreted was 147·9 g. Therefore, the weight of dry matter digested per day = 513·3 g, and the percentage digestibility of the *dry matter* $= 513{\cdot}3 \times 100/661{\cdot}2 = 77{\cdot}6$.

The dry matter of the silage and faeces contained respectively 11·0 and 17·9 per cent of crude protein, so that the total weight of protein consumed per day $= 661{\cdot}2 \times 11/100 = 72{\cdot}7$ g, and the total weight of protein excreted per day $= 147{\cdot}9 \times 17{\cdot}9/100 = 26{\cdot}5$ g.

Therefore, the crude protein digested $= 72{\cdot}7 - 26{\cdot}5 = 46{\cdot}2$ g, and the percentage digestibility of the *crude protein* $= 46{\cdot}2 \times 100/72{\cdot}7 = 63{\cdot}5$

The percentage figures so obtained are known as "digestibility coefficients" or "coefficients of digestibility", and are calculated for the other constituents of feeding stuffs in the same way. It is assumed that the solid excrements are entirely indigestible; actually, certain amounts of digestible constituents are voided with the faeces, and the coefficients of digestibility are slightly lower than the true values. The percentages of digestible constituents present in feeding stuffs are calculated by multiplying the total percentages determined by analysis by the corresponding digestibility coefficients.

Because of the laborious nature of animal digestibility experiments, attempts have been made to determine digestibility by laboratory methods, but with little success. The most useful is the Wedemeyer modification of the method devised by Stutzer to determine the "digestibility" of protein. A known weight of feeding stuff is treated with a solution of pepsin in dilute HCl and, after incubation at 37°C for 48 hours, the protein content of the insoluble residue is determined by the usual Kjeldahl method. The pepsin-HCl soluble protein is calculated by subtracting the result from the total protein content. While the method has a limited value for comparative purposes, the result obtained varies with the degree of fineness to which the food is ground and with the conditions of drying. Thus the pepsin-HCl solubility increases with fineness of grinding, but is depressed by prolonged oven-drying.

Factors affecting digestibility

In the first place, it is important to realise that individual animals of the same species differ in their ability to digest a given food, so that, in a

group of animals, one may persistently digest a larger proportion of the food constituents. Young and mature animals apparently differ but little in digestive power, and Kellner found that food given to sheep was digested equally well at the age of 6 months as it was 8 months later. Very young animals, however, cannot cope with coarse or hard food because their digestive system is incompletely developed.

A starving animal may not digest more food than one adequately fed, but overfeeding, especially with a rich diet, may seriously diminish the proportion digested.

The influence of exercise and work does not appear to be great. The following is a summary of numerous experiments carried out in Paris by Grandeau and Leclere with cab horses.[1]

	Food digested		*Food digested*
At rest	1000	Trotting	976
Walking exercise ..	1032	At work trotting	973
At work, walking	1007	At work in cab ..	959

Generally speaking, gentle exercise appears to improve an animal's digestive capacity, whereas very hard work may have the reverse effect.

With regard to the food itself, several circumstances affect its digestibility. One of the most important is its fibre content and the higher this is the lower is the digestibility. The tough fibrous tissues are comparatively indigestible ; they also enclose the more digestible constituents and render them less accessible to the digestive juices. The fibre content is closely related to the maturity of fodder plants. It increases considerably with maturity, and this is accompanied by a decrease in digestibility of all food constituents, as shown by the following data which represent the percentage composition of the dry matter of hay cut from the same field on the dates indicated ; the figures in parenthesis are the corresponding digestibility coefficients—

TABLE 3 [2]

Date of cutting	Nitrogenous substances	Ether extract	Soluble carbo-hydrates	Fibre	Digestibility of the organic matter
May 14th	17·7 (73·3)	3·2 (65·4)	40·8 (75·7)	23·0 (79·5)	(75·8)
June 9th	11·2 (72·1)	2·7 (51·6)	43·2 (61·9)	34·9 (65·7)	(64·3)
,, 26th	8·5 (55·5)	2·7 (43·3)	43·3 (55·7)	38·2 (61·1)	(57·5)

[1] WARINGTON, R, 1919, "Chemistry of the farm," p. 150 (Vinton and Co. Ltd., London).

[2] *Ibid.*, pp. 138 and 151.

It will be noticed that the fibre itself becomes less digestible with age. The herbage cut on May 14th represents grass grazed in the green state by stock, that cut on June 9th and 26th respectively, good ordinary hay and over-ripe hay somewhat coarse and stemmy but well harvested.

It is sometimes thought that the digestibility of roughages such as hay and straw is increased by grinding and chaffing, whereas there is a good deal of experimental evidence to show that this is not so. However, animals expend less energy in consuming and masticating milled or finely chopped roughages and, in consequence, they have a somewhat higher feeding value than long hay and straw. The modern hammer mill reduces them to a finely divided condition, but such treatment is hardly justified when the additional expense is taken into account.

Indeed, grinding to a fine state of division may have an adverse effect on digestibility, especially in the case of mealy foods which may assume a doughy consistency in the stomach, and become relatively impervious to the gastric juice. Any means of overcoming this tendency will be advantageous, and fine meals are often mixed with more fibrous substances such as chaff and bran. On the other hand, grains with hard coats such as oats, barley, maize, beans and peas may pass through the animal intact unless they are well masticated. Soaking aids mastication and whole grains are soaked for feeding to sows, but it is worth while preparing grains by crushing or cracking in order to ensure efficient digestion by cattle, sheep and horses. Poultry receive grains whole or as meal, and grain is usually finely ground for pigs.

The past history of food, including the method of preparation, is important. One of the great disadvantages of overheating during ensilage is the extent to which protein digestibility is depressed, and well-preserved silage is an excellent source of high quality protein, whereas this constituent is almost valueless in badly heated silage. Fodder crops suffer comparatively little decrease in digestibility when made into hay under favourable conditions, but in unfavourable seasons a very inferior fodder results. This is due, not only to impaired digestibility, but to the shedding of much rich leafy material during excessive turning, raking, etc, and to the leaching effect of rain. In the stack, heating lowers the digestibility of the protein, but renders the fibre and soluble carbohydrates more digestible.

From time to time attempts have been made to increase the digestibility of straw by chemical treatment with sodium hydroxide, sodium carbonate, calcium hydroxide and the mineral acids. The most successful is the method devised by Beckmann in which straw, chaffed into lengths of 2-3 inches, is treated for a minimum of three hours with a 1·5 per cent solution of caustic soda, and afterwards washed free from alkali. Although the treatment results in an almost complete loss of protein, together with losses

of dry matter, lignin is removed to such an extent that the cellulose is rendered much more digestible, and the straw pulp produced has a considerably higher feeding value than the original straw. The method was revived and used during the war in order to make better use of the large stocks of straw available.

Much labour has been expended in the past in cooking foods, but the modern trend is to avoid heating or boiling except in specific cases. Under the Foot-and-Mouth Disease (Boiling of Animal Foodstuffs) Order of 1932, it is compulsory to boil swill for animal feeding for at least one hour in order to minimise the spread of foot-and-mouth disease, and boiling is also a precaution against swine fever, while it may be advantageous to offer cooked food to ailing animals in order to tempt them to eat. Boiled potatoes are less liable to upset the digestive system of the pig and have a higher digestibility than the raw tubers. In general, cooking increases the digestibility of large starch grains by causing them to swell and burst, and also softens tough fibrous constituents, but impairs the digestibility of protein. The fact that cooking often improves palatability may be a disadvantage, in that it encourages animals to bolt their food or consume undesirably large amounts of poor quality foods and, except in such specific cases as those mentioned above, cooking has little to recommend it.

Another factor of importance is the rate of passage through the alimentary canal. As was pointed out in the previous chapter, the enzyme rennin curdles milk in the stomach to retard its passage into the small intestine and so enables enzyme action to have full play, a function of particular significance in the incompletely developed digestive system of young animals. Very succulent immature foods may, by inducing scouring, adversely affect digestion, and foods with a costive or binding action on the other hand upset the normal rate of digestion and lead to physiological upset.

Finally, one must not forget the difference in the ability of ruminants and non-ruminants to digest fibrous foods, the pig, in particular, being able to deal with strictly limited quantities of fibre, while the horse can cope with relatively larger amounts because it possesses a large caecum.

CHAPTER 8

SUCCULENT FOODS

(1) GRASSLAND HERBAGE

The farmer has a wide selection of feeding stuffs at his disposal, and his choice of foods for a particular purpose will depend upon their characteristic properties, their relative abundance and cost. While it is not possible here to describe all the foods available, a knowledge of the properties of the most important types is fundamental to successful rationing.

In Chapter 1 it was pointed out that foods vary greatly in their content of various constituents. Perhaps the most marked difference is in moisture content, and this enables a broad classification into succulent and non-succulent or " dry " foods. Since the value of feeding stuffs depends on the nature and amount of dry matter present, it is customary to refer to the percentage of dry matter rather than to the moisture content. Succulent foods are poor in dry matter, which varies from less than 10 to about 30 per cent. Most " dry " foods, on the other hand, contain 85 to 90 per cent, and may be classified according to their richness in various constituents. The roughages, comprising hays and straws, are relatively rich in fibre, which varies from less than 20 to more than 40 per cent, whereas concentrated foods are rich in soluble carbohydrates, protein or oil, and poor in fibre. Thus cereal grains and their products are rich in starch, oil cakes and meals are rich in protein and some of them in oil as well. The following descriptions are confined mainly to the general properties of feeding stuffs. Details of their composition and nutritive value are given in the appendix to which constant reference should be made.

Succulent foods

Succulent foods comprise grassland herbage, silage, forage crops and roots. Grassland herbage contains about 20 per cent of dry matter, but may contain more or less according to its stage of maturity, roots contain about 10 per cent, and silage and forage crops 15 to 30 per cent. While all are important foods, grassland herbage is pre-eminent, for it is the natural food of the grazing animal and has been estimated to provide some two-thirds of the total food of British livestock.

Grassland herbage

Despite the fact that data giving the composition of hay have been available for a long time, it was not until the third decade of the present century that detailed investigation of the chemical composition of grassland herbage was initiated by Fagan at Aberystwyth and Woodman at Cambridge. The work carried out at these and other centres has provided valuable information regarding the factors responsible for the great variation in yield and chemical composition. It is well known that several acres of poor hill grazings are necessary to sustain a single sheep, while the best types of lowland pastures are capable of fattening 6 sheep per acre. Chemical analysis has revealed marked variation in composition between these and other types of pastures, and a table illustrating this fact is given on p. 31. Moreover, this variation in chemical composition is apparent, not only in different fields on the same farm, but also in the herbage of any one field.

The chemical composition and nutritive value of grassland herbage is greatly influenced by management, a detailed description of which will be found in " Grassland, its management and improvement " by Stapledon and Hanley. It has been shown that it is possible, by management alone, to bring about very wide variations in the botanical composition of a sward with a corresponding effect upon the nutritive value of the herbage.([1])

One of the outstanding features of grassland herbage is its great abundance during May and June, with a less marked " flush " about September, and the absence of appreciable growth between the end of October and the beginning of April. The pronounced midsummer flush of grass is accompanied by increasing stemminess and development of flower and seed. Thus, while the dry matter of young grass is rich in protein, the amount decreases very rapidly with advancing maturity. This is well illustrated by the following table, where the figures refer to the composition of individual species—

TABLE 4([2])—Percentages of dry-matter of grass

Age when cut in months	Meadow foxtail		Cocksfoot		Yorkshire fog		Bent	
	Protein	Fibre	Protein	Fibre	Protein	Fibre	Protein	Fibre
1	17·3	20·1	12·3	21·3	13·5	22·9	14·7	20·0
2	13·1	27·5	11·8	23·0	9·1	29·3	11·0	27·1
3	11·3	28·6	9·1	32·4	5·4	32·7	8·2	30·2

[1]Jones, Martin G., 1933, " Grassland management and its influence on the sward," Parts 1–5, *Emp. J. exp. Agric.*, **1**

[2]Fagan T. W., 1931, " The influence of management on the nutritive value of herbage plants," *Agric. Progr.*, 8, p. 66.

It will be noted that the decline in crude protein is associated with a marked increase in fibre content. The composition of herbage will be influenced also by the type and proportion of the various plant species present. Fagan has shown that meadow foxtail and cocksfoot are superior in protein content to timothy, red fescue and tall oat grass cut at the same stage of growth, and the superiority of clovers and legumes generally over grasses grown under similar conditions is well established. The above table also illustrates a fact of great practical importance, namely, that Yorkshire fog and Bent, two grasses generally regarded as inferior to meadow foxtail and cocksfoot, compare favourably with these at the pasture stage (one month). When closely grazed, such " poor grasses " contribute considerably to the value of the pasture, but deteriorate more rapidly than the better types of grass under less careful management. In the paper referred to above, Fagan showed that advancing maturity is accompanied by a marked increase in the proportion of stem to leaf, with a consequent decrease in protein content and an increase in crude fibre. The following table gives the ratio of stem to leaf in Italian ryegrass cut at weekly and monthly intervals, and the percentage of crude protein and fibre in the dry matter—

TABLE 5

	Average of 24 weekly cuts Ratio of stem to leaf 1 : 3		Average of 6 monthly cuts Ratio of stem to leaf 1 : 1·4	
	Percentage in Stem	Leaf	Percentage in Stem	Leaf
Protein ...	15·0	22·9	10·6	16·0
Fibre ...	26·2	20·2	29·1	23·6

These figures, which show that frequent cutting secures a leafy product rich in protein, are all the more striking when one realises that the monthly cut grass is still leafy in comparison with more mature herbage. The practical importance of this lies in the realisation that the efficient use of pasture depends upon intensive grazing coupled with adequate manuring, but it must be remembered that frequent cutting checks growth to such an extent that high quality is obtained at the expense of bulk. When both are taken into account, the best results are generally obtained by grazing at intervals of 3 to 4 weeks, keeping a watchful eye on the sward, and

adjusting the head of stock so as to prevent the development of coarse tufted herbage on the one hand and overgrazing on the other.

Where climatic and soil conditions permit, a system of rotational grazing may be adopted. For this purpose a suitable pasture is divided into 6 or 8 fenced paddocks, each supplied with water. The soil is adequately limed, and given a liberal dressing of basic slag or superphosphate late in the autumn to encourage the growth of the better quality grasses and clovers which will not thrive if lime or phosphates are deficient. Lime and phosphates also increase the mineral content of the herbage. Fairly intensive nitrogenous manuring is employed in order to increase the bulk of leafy herbage and to extend the grazing season. Paddock 1 receives sulphate of ammonia at the rate of 1 cwt per acre in the spring, and at intervals of a week the other paddocks are in turn similarly treated. A further two dressings at the same rate are applied during the grazing season. There appears to be less need for potash, much of which is returned in the urine of grazing animals, but where application is necessary, the quality of the herbage is thereby improved. Grassland generally predominates on the heavier soils, and these are naturally well supplied with potash.

When the herbage has grown sufficiently, dairy cows are turned into paddock 1, and after a period of 3-6 days, when the best herbage has been consumed, they are moved into paddock 2. The first paddock is then grazed bare by followers, store cattle, dry heifers and young stock, which are in turn moved to the other paddocks. In this way the dairy cows receive the best herbage, and return to each paddock at intervals of 3-4 weeks. Where conditions favour a continuous growth of luscious grass, it is possible to make very efficient use of herbage by rotational grazing, and to carry a larger head of stock, but where rainfall is low and growth uncertain, the response is insufficient to compensate for the cost of fencing, manuring and laying-on of water.

Any system of grazing requires careful planning and strict attention to detail if the herbage is to be maintained in a highly nutritious condition. The grazing season may be roughly divided into three periods, the pre-hay, hay and aftermath periods. Chemical analysis has shown that the best herbage is grown in the first period. The protein content decreases and the fibre increases during the second period, while the quality improves again in the third period, but rarely attains that of the spring herbage. Grazing has to be very skilfully managed if best use is to be made of the pasture. During the pre-hay period, when growth is vigorous, it may be necessary to increase the head of stock to prevent the herbage "running away" from them and becoming stemmy, with a tendency to suppress the growth of wild white clover. On the contrary, overgrazing

must be avoided lest the growth of the better grasses and clovers is checked and poorer grasses and weeds encouraged. Poaching of the surface soil may occur under wet conditions producing unevenness, bare patches and weed development. Again, coarse patches or tufts are common due to the fact that animals are selective in their grazing and reluctant to consume herbage in the vicinity of their own droppings. The horse grazes closely and tends to manure a section of a field, sheep too are close grazers and avoid the tall herbage which is consumed by cattle. It is best to practice mixed grazing or alternate grazing by different classes of animals, and droppings should be spread by means of a chain harrow. When it is necessary to supply food or water in troughs, these should be moved frequently to avoid accumulations of droppings in restricted areas. Despite all precautions, the herbage may become stemmy and tufted, and it should then be removed with a mowing machine.

From what has been said above it is obvious that the production of herbage of high quality throughout the season calls for great skill on the part of the farmer, but there is no doubt that when successful his efforts are amply rewarded for, as stated by Woodman, " it may be asserted that the farmer's best and cheapest protein concentrate is to be found growing within reach of the homestead."([3])

The dry matter of closely grazed grassland herbage is, in fact, a concentrated food of great value. When grazed at three-weekly and monthly intervals, the dry matter contains on an average 22·5 and 17·5 per cent of protein respectively, the former approximating to linseed cake in this respect (24·2 per cent) while younger herbage may contain more than 30 per cent of protein. These figures are expressed on a dry matter basis, whereas, in succulent grass containing four-fifths of its weight of water, the actual protein content in the two former cases would be 4·5 and 3·5 per cent respectively. Furthermore, the protein is of high biological value and it appears that spring grass is slightly superior to autumn grass in this respect. It is pointed out in Chapter 17 that closely grazed grassland herbage is capable of maintaining a dairy cow and providing for the production of 5 gallons of milk ; further, that the protein is in excess of such requirements. When, therefore, it is desirable to supplement such herbage, foods low in protein such as cereal products suffice.

Not only is the dry matter of young herbage a protein concentrate ; it is a unique concentrated food for at least three reasons. In the first place, it is an excellent source of phosphate, lime and also potash. Most concentrated foods, on the other hand, are badly balanced in their content

---

[3]Woodman, H. E., Blunt, D. L. and Stewart, J., 1926, " Nutritive value of pasture," *J. agric. Sci.*, p. 246.

of phosphate and lime—the cereal grains are relatively rich in phosphate and very poor in lime. Secondly, green herbage is rich in carotene, and this the animal converts into vitamin A, whereas cakes and meals contain little if any carotene. Moreover, there is a great difference in fibre, for the dry matter of grassland herbage is much more fibrous than most concentrated foods. This is not a serious disadvantage, however, for in the immature plants lignification has not occured. In fact, the fibre is highly digestible—to the extent of 75-80 per cent—and is an important source of carbohydrate. It will be seen, therefore, that the dry matter of grass has special merits and none of the disadvantages of other concentrated foods ; indeed, one may regard it as the concentrate *par excellence.* It is not surprising that efforts have been made to conserve young grassland herbage with a minimum of loss for winter use. It is converted into two products, namely, silage and dried grass, and a brief description of these products will now be given. The conversion of more mature material into hay will be considered in a later section.

Silage

The process of ensilage consists in preserving green herbage by controlling the air supply and consequently the type of fermentation. For detailed accounts of the process reference should be made to standard works on fodder preservation (see Bibliography). Briefly, it entails the compression of freshly cut herbage (or other suitable crops), in a stack, clamp, pit or silo, which may be a wooden, brick or concrete structure, or a tower capable of holding much larger quantities of material. The type of silage produced depends on the material ensiled, and the conditions under which it is made. Adequate compression restricts respiration of the living cells and loss of carbohydrates, but sufficient air is left in the mass to allow aerobic bacteria to thrive and convert carbohydrates into acetic, propionic and lactic acids. The acidity developed suppresses undesirable fermentation, and it was the realisation of the importance of lactic acid fermentation that led to the addition of diluted molasses to the herbage being ensiled, thus providing readily available carbohydrate, which is of great importance in the ensilage of protein-rich herbage. In some processes, mineral acids are added, e.g., 2N-hydrochloric acid with a little sulphuric acid in the A.I.V. process, and a mixture of hydrochloric acid, phosphoric acid and molasses in the Defu process, while substances producing acids have also been used, such as phosphorus pentachloride in the Penthesta process. The aim is to produce a *p*H of 3–4, below which two undesirable changes are depressed, namely, bacterial fermentation producing butyric acid, and enzymic hydrolysis of protein. In this

country the molasses method has proved to be more practicable than direct addition of acids.

Well-preserved silage has a greenish, golden yellow or light brown colour, a fruity vinegary or sometimes no distinct smell, and a pH of 4 to 5, preferably in the region of 4–4·5. If the herbage ensiled is rather stemmy, or has wilted, adequate compression may be difficult, and excessive respiration leads to overheating and high losses of dry matter. Overheated silage varies in colour from brown or dark-brown to black, and has a smell resembling tobacco, molasses or caramel. The fact that the acidity is not usually different from that of well-preserved silage indicates that pH alone is not a safe criterion of suitable fermentation. Overheated silage is highly palatable to animals, but its protein digestibility is seriously impaired. Compression of stemmy herbage is facilitated by using more water with the molasses, by more thorough treading and by chaffing, but such herbage is more suitable for hay making than ensilage.

On the other hand, the ensilage of very succulent immature or wet herbage may lead to over-compression and underheating. Under the relatively anaerobic conditions produced, butyric acid is formed, and marked hydrolytic and putrefactive changes may produce evil smelling products from the proteins which may be dangerous to animals. Underheated silage has a foul smell, is greenish brown, olive green or dark green in colour, and has a pH of 5 or more. Much can be done to avoid undesirable fermentation, e.g., by reducing the amount of water, treading lightly and filling the silo slowly.

Well made silage, especially that made from young grass and clover, is an excellent food approximating in nutritive value to the material from which it was made. Good quality herbage from permanent pastures or young leys should be used for the purpose, and it should be realised that ensilage is not merely an alternative to hay making, but a means of preserving protein-rich herbage. One may sum up the nutritive value of good silage by saying that, as a foodstuff, it possesses most of the virtues of the original herbage, including appreciable conservation of the carotene, which is largely destroyed in overheated silage.

Certain losses of nutrients are inevitable whatever method is employed, and the extent of these depends on the suitability of the material ensiled, and the care taken in filling and sealing the silo. Unfortunately, extensive wastage around the sides of the silo is not uncommon, due to entry of air and rain, and development of moulds. The edge waste may penetrate into the silage to a depth of 1–1½ feet in extreme cases ; more generally, it amounts to about 6 inches and may be absent altogether. The losses incurred in this way are so obvious that they militate against the more

widespread practice of ensilage ; on the other hand, the farmer is often oblivious of the losses accompanying hay making, which are less apparent but often serious.

Watson has collected data for the losses incurred in the various processes of fodder conservation, and his results are shown for comparative purposes in Table 6.

TABLE 6[4]—Losses of nutrients involved in hay making, artificial drying and ensilage

(Stated as percentages of the original crop)

	Dry matter	Starch equivalent	Digestible crude protein
Artificially dried crop ...	7·5	11·5	8·2
Ordinary silage	15·9	34·3	39·8
Stimulated silage (added sugar, whey, etc.)	11·7	22·9	10·0
Acidified silage	12·4	23·7	10·0
Hay made with special appliances	17·4	38·2	25·3
Hay made on the ground ...	22·1	43·9	34·6

The data are not confined to grassland herbage but apply also to forage crops. In the case of artificial drying the figures are based on two tests only, and are probably on the high side. It will be noted that ensilage occupies a position intermediate between artificial drying and hay making.

The feeding of silage

While overheated silage is little more than a roughage, well-preserved silage of high protein content may be used to replace concentrated foods, and is fed to cattle at the rate of 20–40 lb or more per head daily. It is an excellent food for cattle and sheep, and has a laxative effect. Horses and even sows may receive small quantities as a tonic. The composition of silage varies widely as shown in Table 7 giving results obtained during 1940 and 1941.

[4] WATSON, S. J., 1939, "The science and practice of conservation : grass and forage crops," Vol. 2, p. 737 (London, *The Fertiliser and Feeding Stuffs Journal*)

TABLE 7 [5]

Type of material	No of centres	*p*H	Percentage	
			Dry matter	Crude protein in the dry matter
Grass	122	Max. 7·2	41·9	21·9
		Min. 3·4	14·5	8·7
		Av. 4·7	23·8	13·8
Grass and clover	76	Max. 6·2	35·7	22·4
		Min. 3·5	13·7	10·2
		Av. 4·8	25·0	16·5
Cereals and legumes	53	Max. 6·2	35·5	18·0
		Min. 3·3	12·3	7·5
		Av. 4·5	24·3	12·1

The figures show that the dry matter of silage may be a protein concentrate when made from any of the above materials; also, that grass and clover give a richer product than grass alone, but where mature material is used the product may be of poor feeding value and merely a hay substitute. The comparatively low average protein in the cereal-legume silage was due to the use of rather mature material and the low proportion of legumes present. The possibility of such wide variation in compositon, and its obvious effect upon feeding value, should always be kept in mind when referring to the average figures given for silage and similar foods.

Finally, as already mentioned, silage may be made from a variety of crops, the principles involved being much the same as those described. The composition of some of these silages is given in the appendix.

Dried grass

Although not a succulent food, dried grass will be considered briefly here because, apart from moisture content, it is very similar to the herbage from which it is produced. The practice of grass drying is a direct outcome of the investigations into the chemical composition and nutritive value of young leafy grass referred to in the foregoing sections, as a result of which it was realised that the dry matter of such herbage compared favourably in protein content with many concentrated foods.

A good deal of attention was given to methods of drying grass in the years immediately preceding the recent war. The driers used varied considerably in type, but resembled one another in possessing a chamber

[5] Davies, R. O., and Ashton, W. M., 1943, " The making and feeding of silage in Mid-Wales," *Welsh J. Agric.*, **17**, p. 93

in which the herbage was dried by a current of hot air, either immediately after cutting or after a period of wilting. In some driers the grass is dried on an endless band, while many contain two chambers, and the herbage is dried in two stages. The fresh grass is placed in the second compartment and partially dried by the hot gases which have already passed through grass in the final stages of drying in the first compartment. The latter is then removed and replaced by that in compartment 2 which is now filled with fresh grass. During the process, the original moisture content of 70–80 per cent is reduced to about 2–10 per cent. The product is either baled or ground into meal, and during storage the outer layers of the bale absorb moisture. Unbaled material will absorb about 10–15 per cent of moisture.

Artificial drying eliminates to a large extent the losses of dry matter which occur during ensilage and hay making. Since the herbage is gathered and carried moist, no loss of dry brittle leafy material occurs, and losses due to respiration in the field and fermentation in the stack are minimised. It is, therefore, the ideal method of preserving grassland herbage, but many difficulties will have to be overcome before the process can become of more general application. Unfortunately, the process is expensive, for at present (1950) one popular drier costs about £1000, and when other essentials are considered, e.g., a Dutch barn for housing the drier and baling or grinding machinery, the cost is about £2,000. This drier produces about 4–6 cwt of dried grass per hour, depending upon whether the herbage was wilted or dried immediately after cutting. Wilting for about 24 hours may reduce the ratio of moisture to dry matter from 4 : 1 or more to about 2 : 1, and hence decreases the cost of drying without seriously impairing the content of carotene or protein. The cost of producing a ton of dried grass in 1936 was estimated at £5–£6, taking into account the cost of labour, fuel, manures, rent and depreciation.([6]) At present the cost is at least twice and, generally, about three times as great.

Apart from the question of cost, the management of grassland which is to provide the necessary herbage constitutes a special problem, for it is unlikely that any pastures could withstand repeated cutting without suffering serious damage.

Chemical composition and nutritive value of dried grass

It cannot be too strongly emphasised that to produce first quality dried grass, the herbage from which it is produced must also be first class, taken from well-managed pastures and leys containing a balanced mixture of leafy grasses and clovers. It is from such herbage, cut at the appropriate

[6]Roberts, E. J., 1937, " Grass Drying," *A.R.C. Report Series No.* 2, p. 104 (H.M. Sta. Office)

time, that the true protein concentrate suitable for replacing purchased cake is obtained. Moreover, the quality of the product must be high in order to justify the comparatively high cost of drying. As is the case with most home grown foods, the product has proved to be very variable in quality, and the Grass Driers' Association found it necessary to grade the product in the following way—

Grade 1	containing	17 per cent or more	of crude	protein	in the	dry	matter
Grade 2	,,	14–17	,,	,,	,,	,,	,,
Grade 3	,,	12–14	,,	,,	,,	,,	,,
Super hay	,,	8–12	,,	,,	,,	,,	,,

The disappointing results obtained have been illustrated by Roberts in a summary of the information obtained up to 1939 at 7 centres.([7]) The proportion of grade 1 samples varied from nil to 41 per cent, showing that the need for cutting the herbage at an early stage of growth has not been fully realised.

What has been said about the high nutritive value of young grassland herbage applies equally to the dried product, namely, richness in protein, minerals and carotene. It has already been pointed out that artificial drying is effected with small losses of dry matter. It also involves comparatively small losses in carotene. In an investigation by Fagan and Ashton, losses of carotene were as low as 10 per cent, but the fact that the maximum loss amounted to 60 per cent, shows that great care should be exercised to minimise this loss ([8]). On an average one-third of the carotene was destroyed. During storage further destruction may occur due to oxidation ; it is accelerated by aeration and a rise in temperature, so that the comparatively loosely packed grass at the outside of bales suffers extensive losses of carotene, while this constituent is largely conserved in the interior of tightly compressed bales. Dried grass should be a much richer source of carotene than most forms of silage and hay. Feeding trials have shown that the colour of both milk and butter is improved when dried grass is fed.

It can be fed with perfect safety to all classes of farm animals. The bales should be opened some 12–24 hours prior to feeding to allow absorption of moisture, because the material from freshly opened bales may be so brittle that animals are reluctant to eat it. Like other concentrated foods, it should be gradually introduced to the ration. In feeding dairy cattle 4 lb of the 1st grade product replaces $3\frac{1}{2}$ lb of balanced concentrates for

[7] ROBERTS, E. J., 1939, " Fodder conservation with special reference to grass drying," *A.R.C. Report Series No.* 5, p. 10 (H.M. Sta. Office)

[8] FAGAN, T. W., and ASHTON, W. M., 1938, " The effect of partial field drying and artificial drying on the chemical composition of grass," *Welsh J. Agric.*, **14**, p. 160

milk production. Medium quality dried grass is fed to cows giving medium yields of milk, while low yielders receive " super hay ". For high yielders hay may be replaced entirely with first-grade dried grass, and theoretically this food suffices to produce up to 6 gallons of milk, but in practice it is difficult to get cows to eat sufficient quantities, as dried grass is a comparatively bulky food. Fattening cattle, sheep and horses may also receive this food, and in the form of meal it is used to the extent of 2–7 per cent of the rations of pigs and poultry. Dried clover and lucerne are also excellent for this purpose.

CHAPTER 9

SUCCULENT FOODS

(2) FORAGE CROPS, ROOTS AND TUBERS

Forage crops

THESE include gramineous, leguminous and brassica crops grown for grazing or soiling, that is, cutting and feeding in the green state. Many advantages attend the growing of forage crops, one of the most important being that they provide valuable food when grass is scarce. Thus, kale is grown for winter feeding, while lucerne is drought resistant and available when pastures are scorched. When forage crops are available stock are not put to pasture so early ; the grass thus gets a better start and provides more grazing throughout the season. They also enable the expenditure on concentrated foods to be reduced and an increased head of stock to be kept for, in many cases, two crops can be grown in the year.

Forage crops possess many of the advantages of pasture herbage. They are highly digestible succulent foods, and in the green state provide abundant carotene. They are also excellent sources of minerals, especially calcium, and of protein. In their action on the bowels too they resemble grassland herbage. Those most commonly grown in Britain are—

Gramineae—Italian ryegrass, rye, barley and oats.
Leguminosae—lucerne, (alfalfa), sainfoin, clovers, vetches or tares.
Brassiceae—cabbage, kale, kohl rabi and rape.

They may be grown alone, or as mixtures of legumes with non-legumes, when the leguminous plants enhance the feeding value and also increase the nitrogen content of the soil for succeeding crops.

Italian ryegrass is one of the most valuable plants used in alternate husbandry and requires rich, deep soil well supplied with moisture. It makes rapid growth, is very palatable and capable of giving very high yields of herbage equally valuable for grazing, soiling and hay making. When sown alone it responds well to nitrogenous manuring, and provides keep in early spring and late autumn. Three or four crops may be taken in the season, and it recovers well from cutting or grazing. The heaviest yields are obtained during the year of sowing, and it is frequently sown with red clover in leys of one or two years' duration. It is not suitable for permanent leys as it dies out during or soon after the second season. Mixtures of Italian ryegrass with oats, barley, rye and vetches are utilised as green forage or made into silage.

Rye is grown in this country not, to any extent, for its grain but as a green crop for soiling or spring grazing. It should be fed before the ear appears, otherwise it becomes coarse and unpalatable to stock. In association with vetches, it is greatly relished by dairy cows and helps to maintain a good yield of milk. Rye is more hardy than other cereal crops, and will thrive on light soils and under conditions of considerable lime deficiency.

Leguminous crops.—These comprise lucerne, sainfoin, clovers and vetches. They are characterised by their richness in protein and lime. In Britain, lucerne is grown mainly in the south-eastern counties of England. Failure is often due to the absence in the soil of the specific nodule bacteria and, when sown for the first time in any area, the seed should be inoculated with the appropriate cultures. The crop is very drought resistant, and is invaluable for feeding dairy cows when pastures are bare or scorched. It is also converted into hay and silage, or dried and ground to a meal, which is very popular as a constituent of rations for poultry and pigs. Lucerne is an excellent green food for all classes of farm animals. It should be cut in the early flowering period and fed as soilage. During and after flowering, lucerne becomes fibrous and less digestible due to lignification of the stems, and Woodman has shown that it differs markedly from grasses, which, at a similar stage of growth, are largely unlignified and highly digestible. ([1])

Sainfoin too is grown mainly in the south-eastern counties, and resembles lucerne in feeding value and in being drought resistant. It is best suited for grazing, whereas lucerne is liable to suffer damage to the crowns when closely grazed. Sainfoin, like alsike, is used to replace clover on clover-sick land. Of the two distinct varieties, giant sainfoin yields the greatest bulk, is less persistent and is used for hay ; common sainfoin is chiefly used for grazing.

Crimson clover is grown for grazing or soiling and resembles sainfoin in feeding value. It must not be allowed to become over-ripe, as the very hairy flowers may form balls in the intestines and prove fatal to stock. There are two cultivated varieties of red clover. Early flowering or broad red clover is short lived and does not withstand heavy grazing. It is useful in one year leys and yields heavily. Late flowering red clover is more persistent and resistant to grazing. Red clover is used for grazing, soiling or hay making. For the latter purpose it is frequently sown with Italian ryegrass and harvested as very valuable seeds hay. Alsike clover somewhat resembles late flowering red clover, gives a good crop of hay but poor aftermath, and will grow at high altitudes and under heavy rainfall conditions that make red clover an uncertain crop.

---

[1] WOODMAN, H. E., EVANS, R. E., and NORMAN, D. B., 1933, "Nutritive value of lucerne," *J. agric. Sci.*, p. 419

Vetches or tares are grown alone or mixed with peas, beans, oats or rye. They are used for grazing, soiling, hay making or ensilage, and, when mixed with oats or rye, enhance the protein content of the fodder. For successful growth these leguminous crops require soil well supplied with lime, and may fail altogether under acid conditions.

Brassica crops include cabbages, kales, kohl rabi and rape, all valuable for autumn and winter feeding. Cabbages provide leafy, palatable food for all classes of stock. Up to 60lb per head daily are given to dairy cows preferably immediately after milking to avoid any risk of tainting the milk when large quantities are fed. They must be fed in a fresh condition as they deteriorate after cutting, and the byre should be cleared of uneaten residues. Cabbages are very useful for sheep feeding, especially for ewes which are being flushed, suckled or fattened, and for crone ewes with broken mouths. In feeding value they are superior to roots, particularly in protein content, but cannot be stored, although they have been converted successfully into A.I.V. silage.

In the past kale was grown mainly for sheep-folding, but has now become very popular for feeding to dairy cows. The two most common types are marrow-stem and thousand-headed kale. The former is a cross between thousand-headed kale and kohl rabi. It possesses a swollen stem filled with marrow, and produces yields of 20 or even 30 tons per acre of green fodder. It is less winter-hardy than thousand-headed kale and is usually fed up to about Christmas, whereas the latter is used between Christmas and Easter but does not produce such a bulky crop. Rape kale and hungry-gap kale are still more winter-hardy, but produce much smaller yields per acre. The kales are an excellent source of protein and minerals, for the dry matter is rich in protein, calcium, phosphorus, potash, chlorine and sulphur. They also provide carotene and vitamin C, and excel as winter food for milk production, being superior to roots for this purpose.

The stems of marrow-stem kale (and to a lesser extent thousand-headed kale) contain very succulent marrow. Woodman has shown that this contains less than 10 per cent of dry matter, more than half of which consists of invert sugar and sucrose in the proportion of about 4 : 1, the marrow of thousand-headed kale containing more dry matter and nearly as much sugar as that of marrow-stem kale.(2) During recent years marrow-stem kale has been converted into silage with great success in many areas. For this purpose it is often mixed with about 5 per cent of straw, chaffed and blown by a cutter blower into the silo, and when fed is usually yellow green in colour, and resembles swedes or pickled cabbage in smell. The

[2] Woodman, H. E., Evans, R. E., and Eden, A., 1936, "The composition and nutritive value of marrow-stem kale and thousand-head kale," *J. agric. Sci.*, 26, p. 212

addition of straw lowers the protein content somewhat, but helps to prevent overcompression and absorbs some of the expressed juice.

Rape is sown in April for feeding in late summer and autumn, or in July for use in October and November. It is used mainly for folding sheep, but may be cut for soiling, given in small amounts to pigs, and fed to dairy cows. It resembles the kales in feeding value and is highly laxative. Sheep turned on to rape must be carefully watched for this reason, and allowed only limited quantities at first.

Other green forage crops include kohl rabi, mustard, buckwheat and prickly comfrey. Mention should also be made of sugar beet tops, which comprise the crown and leaves of sugar beet. The crowns contain sugar and the leaves are rich in protein. Sugar beet tops are a valuable food but must be fed with care, for they may impart a fishy taint to milk due to the betaine present (p. 26). The leaves also contain appreciable amounts of oxalic acid, and the tops should be allowed to wilt for about a week, when the amount present decreases considerably. The addition of a little precipitated chalk to the tops is advocated as a precautionary measure.

The use of forage crops in reclaiming hill land

Much attention has been paid during the last 20 years to reclaiming land of low fertility both on lowland and hill grazings. The reclamation work carried out by Stapledon and his colleagues at the Welsh Plant Breeding Station has been directed mainly to the improvement of poor hill grazings, and is summarised in Bulletin 34 of the Imperial Bureau of Pastures and Forage Crops, Aberystwyth, 1945.

The natural vegetation of exposed hill land, at elevations of 1,000ft or more, consists mainly of poor grasses such as sheep's fescue, nardus and molinia. Growth commences late in the spring, the grazing season is short, and the stock-carrying capacity rarely exceeds one sheep per acre. The aim is to introduce superior species of grass and clover, in order to extend the grazing season and provide more abundant keep, but before this can be accomplished, the fertility of the soil must be raised by the addition of phosphates, lime and nitrogenous fertilisers.

The methods employed vary considerably with circumstances, but all involve breaking up the old matted turf by means of heavy implements such as ploughs, harrows and cultivators. Sheep too play an invaluable role, for they help to consolidate the loose broken surface on land where rolling is difficult or impossible. Their dung and urine increase the fertility of the soil and accelerate decomposition of the turf. By this means, and with adequate liming and manuring, conditions are sufficiently improved to enable grass and clover seeds to become established.

It is with a view to intensifying the beneficial effects of sheep that forage crops are used, for they provide food for a much larger number of sheep, which can be successfully fattened on these areas. Such crops include rape, hardy green turnips, mustard, Italian ryegrass, oats and rye. Seeds mixtures containing wild white clover are sown with the forage crop in the first year or subsequent years. The brassicas provide food in the autumn and early winter, while on less exposed areas Italian ryegrass provides early spring keep.

On lowland fields, rape is sown alone or with Italian ryegrass; on the uplands a mixture of rape and turnips is preferable, while on exposed areas turnips replace rape. When cereals are used they are grazed, made into silage—especially when sown along with vetches—or harvested in the ordinary way. Mixtures containing perennial and Italian ryegrass have provided rich grazing within 6–8 weeks of sowing.

Experience has shown that the use of such pioneer crops in land reclamation is definitely worth while, for they help to ensure satisfactory establishment of sown seeds, and avoid the disappointments which have frequently followed attempts to grow cereals and seeds on land of low fertility without preliminary cropping.

Pioneer forage crops including marrow-stem kale, rape, turnips, oats, rye and Italian ryegrass were used in reclaiming some 6,000 acres of land at elevations of 700–1700 feet in Montgomeryshire during the war, land previously dominated by bracken, nardus, fescue and molinia.(3) The extent to which such land may be improved with the aid of forage crops is illustrated by the fact that, in one of these experiments, the keep provided during late summer was such that it could not be adequately utilised by sheep, and cattle were brought to cope with it. Fifty Aberdeen Angus bullocks were fattened on 33 acres of rye and 25 acres of Italian ryegrass in 12 weeks. The only supplementary food given was straw *ad lib.* during the end of the period, and 8 lb of oats per head daily for the last five days, when the weather was particularly cold and the keep almost finished. In the following year the ryegrass formed a good grazing sward and the rye was harvested for seed.

Roots and tubers

Turnips, swedes and mangolds are the chief root crops grown in Britain. They are the most succulent farm crops, and on an average contain the following percentages of dry matter: different varieties of mangolds 10–13; swedes 11·5; turnips 8·5. In assessing their feeding

---

[3]Ellison, W., 1943, "Experiences in land reclamation, Montgomeryshire," *J. R. agric. Soc.*, 104, p. 100

value the general index taken is their dry matter content, and this is subject to fairly wide variation.

As a general rule the larger roots of the same crop contain the lower, and the smaller roots the higher, percentage of dry matter. Wood and Berry found that individual mangold roots were not of the same composition throughout, the percentage of dry matter being least in the middle of the root, increasing toward the outer region and highest at the apex.([4]) A similar variation is found in swedes. When grown in areas of high rainfall in Scotland, Northern England and Wales, roots and tubers contain less dry matter than those from areas of moderate rainfall, a fact which should not be overlooked in constructing rations.

The dry matter of roots and tubers resembles that of cereals in being rich in carbohydrates but poor in protein, oil, fibre and minerals. The main difference is in the nature of the carbohydrate which, in the potato, consists almost entirely of starch and, in roots, is mainly glucose with smaller amounts of sucrose—although the sugar of mangolds is mainly sucrose, part of which is converted during storage into glucose and fructose without loss of nutritive value. A high proportion of the nitrogen is present in the form of amides, and potash predominates over all other ash constituents. The flavour of turnips and other crucifers is due to the presence of small amounts of oil of garlic, allyl sulphide $(C_3H_5)_2S$, and of mustard oil, allyl isothiocyanate C_3H_5CNS.

Apart from the comparatively small amount of turnips sold for human consumption, the whole crop is fed to stock, principally cattle and sheep. Pigs may receive turnips and swedes when green foods are scarce. The white and yellow fleshed turnips do not lend themselves to storage for any length of time, and are the first of the root crops to be consumed. Turnips are a favourite food for sheep, and in late autumn fattening hogs and ewes to be flushed prior to mating are turned on to growing crops of white and yellow turnips.

Swedes should not be fed for some time after lifting as they are liable to cause scouring, and mangolds cannot be fed with safety until after Christmas for the same reason (see also p. 25). They are the last of the roots to be consumed, and during storage the nitrate nitrogen is slowly converted into amides. Mangolds may be fed to all classes of farm animals but the bulk is fed to cattle. While some authorities consider that mangolds, especially when grown on chalk soils, cause the blocking of the urethras of male sheep with urinary calculi, others doubt the accuracy of this assumption.

[4] Wood, T. B., and Berry, R. A., 1905–6, "Variation in the chemical composition of mangels," *J. agric. Sci.*, 1, p. 176

When fed in large quantities to dairy cows, roots are reputed to stimulate milk secretion and to yield more watery milk. The results of careful feeding experiments conducted by Lauder, Fagan and others have shown the latter assumption to be erroneous. It was found that cows receiving 112 lb of roots per day gave a lower yield of milk richer in fat than cows receiving half this amount. Swedes and turnips may impart their characteristic taint to milk whereas mangolds are less prone to do so. In the past as much as 2 cwt of mangolds and 1 cwt of swedes have been fed to cattle, but the present tendency is to limit the amount to some 40-60 lb. Store cattle keep in excellent health when fed with straw and roots only.

Potatoes are grown chiefly for human consumption, any surplus being used for farm animals. They are also used as a source of starch and alcohol. On an average they contain about 24 per cent of dry matter. The chief use of potatoes in animal nutrition is to replace meals in pig feeding, 4 lb being approximately equivalent to 1 lb of barley meal, and to obtain the best results they should be cooked, as this increases their value and destroys their laxative effect. They are rarely given to sheep, and cattle should receive limited amounts only of the raw tubers to avoid the animals becoming "blown," perhaps with fatal results. Mature cattle may receive 20 lb with safety but they should be offered in small quantities at first. One pound of potatoes is approximately equivalent to 2 lb of mangolds or swedes.

Potatoes contain a small quantity of a poisonous alkaloid solanine. When potatoes turn green on exposure to sunlight, or sprout, the amount increases and the sprouts may contain about 5 per cent and should never be fed to stock. Green potatoes are apparently less dangerous than the sprouts, but for safety are best withheld, or only fed after boiling and discarding the water.

Woodman and Evans have investigated the feeding value of dried potato products produced in this country from unsaleable and surplus tubers, namely, cossettes, flakes and slices.(5) These products have been shown to be highly digestible and palatable, and superior to barley meal in feeding value, potato slices and flakes comparing favourably with maize meal and flaked maize respectively. For pigs, potato flakes and slices are preferable to ground cossettes (potato meal) which cause digestive disturbances and scouring unless restricted to moderate amounts; for cattle the cossettes and slices are preferred as the flakes tend to become pasty during mastication by ruminants. These products replace equal weights of barley meal in the rations of cattle and sheep.

---

[5] Woodman, H. E., and Evans, R. E., 1943, "Further investigations of the feeding value of artificially dried potatoes: the composition and nutritive value of potato cossettes, potato meal, potato flakes, potato slices and potato dust," *J. agric. Sci.*, 33, p. 1

It is also worthy of mention that potatoes can be ensiled between layers of green crops, when they are partially cooked by the heat developed, or by steaming the washed tubers and pressing the mashed product into a pit and sealing with a layer of soil.

Finally, reference should be made to sugar beet pulp, a by-product used by growers living near sugar beet factories. After removal of some of the water by pressure, the wet pulp contains about 85 per cent. Like other by-products of high moisture content, it decomposes rapidly and must be fed in a fresh condition. Dairy cows may receive 20–30 lb daily and bullocks about double this amount.

Most of the pulp is dried, with or without the addition of molasses; it then resembles oats in feeding value and is also used to replace roots after making due allowance for the differences in moisture content. As previously mentioned the pulp swells very considerably when moistened, and for this reason must be soaked in water before feeding unless fed in very small amounts. Milking cows receive about 6–8 lb and bullocks about 10–12 lb. Sheep, horses and calves may be given small amounts in place of a pound or so of their cereals.

There appears to be little difference in the feeding value of the molassed pulp, which is, however, more palatable because it contains 15–20 per cent of sugar. It must be fed rather more carefully than the unsweetened pulp because it is laxative and may also produce a fishy taint in milk. The protein of sugar beet pulp has a low biological value for milk production and excessive quantities of pulp are reputed to produce hard butter, white in colour and of poor flavour.

Beet molasses contains about 25 per cent of water and rather more than half its weight of sugar. This is mainly sucrose, whereas, in cane molasses, much of the sweetening matter is in the form of invert sugar. Both types of molasses are used as condiments mixed with chaff or rather unpalatable foods such as palm-kernel cake, for making silage and for binding concentrated foods into cubes. Ruminant animals make little use of molasses as the sugars are largely decomposed by bacteria.

DRY FOODS

THE BULKY FODDERS OR ROUGHAGES

Although referred to as dry foods, these feeding stuffs contain about 10–15 per cent of moisture, which varies in amount with harvesting conditions and atmospheric humidity during storage. They fall into two groups differing greatly in composition and properties, namely, the bulky fodders or roughages, and the concentrated foods. The former are characterised by their high fibre and low protein content ; the latter generally contain comparatively little fibre and may be rich in one or more of the following, protein, oil and carbohydrate. There are also important differences in mineral content for, although roughages may be a poor source of certain mineral constituents, they are not as badly balanced in this respect as most concentrated foods.

These groups of feeding stuffs play rather different roles in rationing. The roughages make up the bulk of a ration and when fed *ad lib.* they satisfy the appetite. On the contrary, concentrated foods are used in increasing amounts when it is necessary to provide comparatively large quantities of nutrients without overburdening the animal with bulky material, for example, in feeding high yielding dairy cows. They are invaluable for balancing rations and are described in the next chapter.

The roughages

Hay and straw are the most important roughages which also include the chaff of cereals and crops such as linseed.

Hay constitutes the most important food available for winter feeding. Most hay is made from grasses or mixtures of grasses and clover ; meadow hay from permanent pastures, and seeds hay from a crop of grass and clover grown in the arable rotation. Other crops such as red and crimson clover, lucerne, or mixtures of oats and legumes are also made into hay.

The chemical composition and nutritive value of hay depends on a number of factors. Botanical composition is among the most important, for such grasses as Yorkshire fog and bent are inferior to ryegrass, timothy and cocksfoot, and suffer more rapid deterioration becoming very coarse and stemmy as they mature. Further, the protein and lime content will be higher the greater the proportion of clover or other legumes present.

The chemical composition will also depend upon the stage of growth at which the hay was cut, a factor already discussed in connection with grassland herbage (p. 65). Two factors account for the rapid deterioration in feeding value with advancing maturity. In the first place, the fibre increases in amount and becomes less digestible with progressive lignification ; secondly, the nutrients, such as protein, are transferred to the seeds, which may be shed during hay making, or resist digestion by the animal. The general tendency is to allow hay to become too mature and thus secure a large bulk of fodder, and it cannot be too strongly emphasised that this is obtained at the expense of quality. There is little doubt that hay should be cut at an earlier stage of growth than is generally the case, that is, when most of the grasses have reached the flowering stage. In this way a more nutritious product would be secured without undue sacrifice of bulk.

While botanical composition and stage of maturity affect the nutritive value of the standing crop, a third and extremely important factor is the type of weather prevailing during the harvest. In favourable weather hay is often cut and carried within a period of a week or less, but harvesting is often seriously prolonged by wet weather. The crop is then exposed, sometimes for weeks, and repeated leaching with rain washes out much of the protein and minerals, especially phosphates and chlorides. Hay of greatly reduced palatability and feeding value is thus produced and may be fit for use only as litter.

In Scandinavian countries, and to some extent in Scotland, hay cocks are built on wire fences or light metal tripods to allow free circulation of air and facilitate drying. In late districts of Britain, partly dried hay is made into small ricks or pikes large enough to afford protection from rain while allowing free circulation of air. When dry enough the hay is stacked. The method is also used with leafy material, and avoids high mechanical losses.

Baling in the field is a modern development enabling hay to be harvested in a comparatively damp condition—containing as much as 28 per cent of moisture—provided ample ventilation is provided in storage. In experiments at Jealott's Hill, Watson showed that hay containing 20–24 per cent of moisture was best suited for baling ; lower moisture contents resulted in hay of poor colour due to bleaching, and brown fermented patches appeared at a higher moisture content, while hay containing 32–40 per cent became mouldy, dusty and less digestible.(1) Baling is an aid to successful rationing, for knowledge of the approximate weight of a bale facilitates allocation of the hay to stock.

---

[1]Watson, S. J., 1939, "The science and practice of conservation : grass and forage crops," Vol. 1, p. 92 (London, *The Fertiliser and Feeding Stuffs Journal*).

It has been estimated that during hay making and storage the average loss of dry matter amounts to 25 per cent, and that in a bad season 50–60 per cent of the nutritive value is lost. The total losses incurred are threefold in nature. For a considerable time after cutting, the living cells respire, and carbohydrates are oxidised to carbon dioxide and water. Losses of dry matter incurred in this way have been estimated at about 10 per cent on an average. Raking, spreading or tedding involve mechanical losses estimated at 5–10 per cent, but considerably higher losses occur when inclement weather prolongs these operations. Moreover, these losses are the more serious as they involve the nutritious leafy constituents, a difficulty inherent in making hay from leafy herbage, and especially legume hay made from clovers, lucerne or sainfoin. On the other hand much seed is shed from very mature hay. Further losses due to enzyme and bacterial action occur in the stack, where fermentation and, in imperfectly dried hay, respiration cause heating. This leads to destruction of some of the most valuable and readily available nutrients. These losses too have been estimated at 5–10 per cent on an average. When heating is pronounced the hay acquires a characteristic odour and, despite its palatability to stock, is less nutritious than normal hay because—as in overheated silage—protein digestibility is depressed. In some cases the temperature rises to 70°C where part of the hay assumes a dark-brown or even a charred appearance and is practically useless. In more extreme cases spontaneous combustion ensues.

Hay that is stacked in a damp condition ferments excessively and overheats or becomes mouldy ; addition of salt when stacking, at the rate of about 20 lb per ton, helps to check this and improves the palatability. Very slight heating makes the hay very sweet and attractive to stock, but mouldy hay is dangerous as many moulds are poisonous. Such hay has a pronounced musty smell and usually produces clouds of dust-like spores when handled. It is particularly dangerous to horses, and animals should not be induced to eat mouldy hay by adding molasses or other condiments.

For purposes of rationing it is usual to classify meadow hay into three grades, poor, good and very good, containing 7·5, 9·7 and 13·5 per cent of crude protein respectively, and 33·5, 26·3 and 19·3 per cent of crude fibre. These figures illustrate the great variability in composition and, from the analysis of 22 samples made in favourable weather on 15 farms in Great Britain in 1935, Watson and Ferguson([2]) are of the opinion that "a farmer often calls his average hay a good sample in rather an optimistic way." They found that the crude protein varied from 4·1 to 11·0 per cent

[2]Watson, S. J., and Ferguson, W. S., 1937–38, " The nutritive value of meadow hay," *J. Minist. Agric.*, 44, p. 247

(average 7·6), in hay containing 15 per cent of moisture. The importance of this is illustrated in Chapter 17 where it is shown that 40 lb of swedes and 14 lb of poor meadow hay barely suffice to maintain a dairy cow, whereas the same quantities of swedes and very good hay serve to maintain the animal and provide for the production of a gallon of milk.

Seeds hay is obtained by sowing mixtures of grasses and clovers (e.g., Italian ryegrass and red clover), and is less variable in composition than meadow hay. It is important to secure a good proportion of clover by ensuring that the soil is well supplied with lime and phosphate, for this enhances the protein and lime content. Seeds hay tends to be rather stemmy however. On an average it contains 12·0 per cent of protein, 27·5 per cent of fibre and 2 per cent of lime.

The mineral content of hay is of great importance in view of the large bulk consumed. The ash is rather rich in silica, and the content of soluble minerals will depend on the proportion of clover present and the mineral status of the soil. From the analysis of 41 samples of hay from different parts of Britain, Linton showed that the percentage of CaO varied from 0·32 to 2·30 (mean 0·99), and the P_2O_5 from 0·29 to 0·75 (mean 0·46).[3] It is evident that good quality hay can be an excellent source of these important minerals, and the hay made from leguminous crops contained 1·5 to 2 per cent of CaO, whereas the timothy hay was poor in calcium. Linton also showed that a high content of soluble ash generally, but not invariably, implies a high calcium content. He estimated that cows consuming 15lb of hay daily would obtain approximately 42, 66 and 126g CaO from timothy hay, meadow hay and clover hay respectively, differences of considerable significance over a lactation period. He suggests that a good meadow hay should contain at least 4 per cent of silica-free ash, 9·5 per cent of crude protein and not much more than 30 per cent of crude fibre.

Hay is a poor source of carotene, for, unlike successful ensilage and grass drying, hay making involves large losses of carotene, which undergoes oxidation in the field and stack to such an extent that when fed the amount present is very small even when the hay is secured in good condition. In a study of the effect of partial field drying on the composition of grass (*Welsh J. of Agric.*, 1938) Fagan and Ashton found that over 50 per cent of the carotene was destroyed in grass exposed in the field for five days, while under more unfavourable conditions 66 per cent was lost.

Other hays obtained from arable land include those made from Italian ryegrass, oats and vetches, broad red clover, lucerne and sainfoin.

The straws.—Cereal crops and certain legumes are grown to produce seed for feeding to animals and for further crop propagation. This usually

[3] Linton, R. G., and Williamson, G., 1943, "Animal nutrition and veterinary dietetics," p. 177 (Green and Son, Edinburgh)

necessitates growing to complete maturity, when most of the protein, oil and soluble carbohydrates are transferred to the seed. The straw is of poor feeding value, and cereal straws in particular have a very wide nutritive ratio (see Chapter 14) being very poor in digestible protein. Cellulose, the chief constituent, is highly lignified, and of comparatively low digestibility, as are the small amounts of other nutrients present. The ash consists mainly of useless silica, so that it is poor in soluble constituents such as lime and phosphate. Legume straws are, however, quite rich in lime, and pea straw contains 1·60 per cent CaO compared with 0·14 per cent in oat straw. Nevertheless, some straws are useful feeding stuffs, and are fed to animals having low production requirements, stores, low yielding dairy cattle and horses. This enables their large appetites to be satisfied by using smaller amounts of hay which is reserved for more productive animals. The composition of straw will depend on the factors already considered in dealing with hay.

Cereal straws.—Of these, oat straw is by far the most widely used. It is rather more nutritious than wheat or barley straw, because the crop is cut before it is quite mature, and the less highly lignified straw contains a little more digestible protein. The immature straw from some of the later districts in Scotland and Wales may approximate in composition to poor hay. In an investigation carried out by the author it was found that immature straw of four varieties of oats grown in a late district contained 6·6 to 8·3 per cent of crude protein in the dry matter, whereas mature straw of the same varieties grown under lowland conditions contained 2·3 to 3·2 per cent. ([4]) A much higher protein content than the average was also found in straw when, owing to a period of drought, transference of nutrients to the grain appeared to be incomplete, and the dry matter of the straw contained 5·0 to 6·6 per cent of crude protein.

It is also the practice in late areas of Wales and Scotland to grow strigosa oats (*Avena strigosa*) for feeding in the unthreshed condition. The crop is harvested in an immature condition and approximates to average hay in feeding value.

Oat straw is fed long or as chaff mixed with roots for dairy and fattening cattle, after the mixture has been standing for a few hours to soften the straw and improve its palatability. Horses doing light work receive limited amounts of oat straw chaffed and mixed with concentrates to ensure thorough mastication of the latter.

Much less wheat straw is fed to farm animals. It may be fed long to cattle by allowing them to pick out the softer and more leafy tissues.

[4] Ashton, W. M., 1938, " The chemical composition of the grain and straw of varieties of oats bred at the Welsh Plant Breeding Station : comparison with some older varieties," *Emp. J. exp. Agric.*, 6, p. 69

It is much less nutritious than oat straw, is stiffer and is used as litter, for thatching, packing and paper manufacture. As a food for horses it is worse than useless and has a negative net energy value.

Barley is usually harvested when dead ripe, and the straw is consequently of low feeding value. It is preferable to wheat straw but must be fed with care as the awns may enter the eyes of cattle. When undersown with seeds the straw often contains some grasses and clovers, and is then equal to or even more nutritious than oat straw. It is fed mainly to stores and low yielding cattle.

Rye straw is very fibrous and is not used for feeding purposes.

Legume straws comprise pea and bean straw whose value depends mainly on the presence of leaves and pods. They contain more digestible protein than cereal straws, and pea straw may resemble poor quality hay in feeding value. Bean straw is chaffed and fed in restricted amounts to cattle, horses and sheep, and pea straw may be given to any stock except horses ; it is popular as a food for pregnant ewes on grass or roots during the winter when grass is scarce. Legume straws are more liable to mouldiness because they are more difficult to harvest and store in a dry condition than cereal straw, and consequently must be fed with great care. Other straws include those produced when grass, clover and flax are grown for seed. They are poor in feeding value and linseed straw is too fibrous for feeding purposes.

Chaff.—Cereal chaff consists of the glumes together with leafy fragments of various plants, in virtue of which it may surpass straw in feeding value. Barley chaff is less suitable for feeding than oat and wheat chaff, because the awns may pierce the mucous membrane of the mouth. Chaff is usually moistened with water or diluted molasses, or mixed with pulped roots for feeding purposes. It should not be confused with the " chaff " produced by chopping straw by means of a chaff cutter. Linseed chaff is superior in feeding value because it contains leaf fragments, broken pods and some seed. It may contain as much as 3·5 and 5 per cent of protein and oil respectively, but is very fibrous.

CHAPTER 11

THE CONCENTRATED FOODS

The concentrated foods fed to British livestock consist of home grown and imported grains, seeds and fruits, together with a variety of by-products from industries which use the grain, etc., as raw material. Certain animal products also fall into this class.

Carbohydrate-rich foods : cereal grains and their products

The cereal grains are the seeds of various species of gramineae, and are widely used as human food, for stock feeding and in industry. They include wheat, barley, oats and rye, of British and foreign origin, and imported maize, rice, dari and millet. Although each has its characteristic composition, cereal grains possess several properties in common. The predominant constituent is starch which, with closely allied carbohydrates, comprises from about 58 to 78 per cent of the grain, but both oil and protein are rather low and subject to wide variation from one cereal to another. Thus barley contains on an average 1·5 per cent of oil and oats 4·8 per cent, while the percentage of protein varies from 8·3 in rice to 12·1 in wheat. The amount of fibre and ash varies widely because the commercial grain may be naked as in wheat and maize, or enclosed by the glumes as in oats and barley. The ash content is low and badly balanced, being comparatively rich in phosphate and potash, and poor in lime and chloride. The ash of grains with adhering glumes contains more silica than the ash of naked grain.

In addition to being poor in calcium, cereal foods tend to lower the amount of calcium and magnesium absorbed from other foods in the intestines, because the phytic acid present combines with these elements to form phytin, a compound of low solubility. This probably accounts for the rachitogenic effect of cereals, and it may be noted that a good deal of the phosphorus too is present as phytin, the calcium magnesium salt of inositol hexaphosphoric acid. Cereal foods are, however, rich sources of vitamins B and E present in the bran and germ respectively.

Cereal grains are usually stored for a considerable time before use, for if fed prematurely, for instance, within a few months of harvesting, they may cause digestive disturbances. Rye is the most dangerous in this respect, and is also prone to infection with ergot, which contains poisonous alkaloids and may cause abortion.

During periods of national emergency, a farmer may retain only limited amounts of certain cereals for stock feeding unless unsuitable for

milling, brewing and manufacturing human food. The amounts vary from time to time and, of the 1949 crops, all home grown oats, barley, rye and dredge corn containing less than 50 per cent of wheat may be retained, but only one quarter of the wheat and dredge corn containing more than 50 per cent of wheat.

Oats.—The oat grain contains more fibre than other cereal grains, the average percentages being : oats 10·3, barley 4·5, wheat 1·9, rye 1·9, maize 2·2. The proportion of husk to kernel is one of the most important factors taken into consideration in judging the value of a sample of oat grain, and under different conditions of growth the husk may vary from about 20 to 30 per cent of the total weight. The influence which this has on the composition and nutritive value will be apparent from Table 8 giving the average composition of a large number of samples of grain, husk and kernels from a series of separations made by Fagan.

TABLE 8 [1]

	Percentage of					
	Moisture	Oil	Protein	Fibre	Soluble carbo-hydrates	Ash
Grain	13·39	5·62	11·76	9·65	56·88	2·70
Husks	6·32	1·36	2·57	32·91	52·97	3·87
Kernels	8·29	7·65	15·32	2·42	64·32	2·00

Compared with other cereals the grain of oats is a better balanced food. It is very palatable and is fed with great success to horses, cattle, sheep, young calves and foals. Oats are in great demand for feeding to horses and are best fed in the crushed condition. Pigs receive small quantities only of the finely ground product. Oats, either in the form of whole or crushed grains or as Sussex ground oats, are excellent for poultry feeding, and their comparative richness in manganese is a preventative against perosis or slipped tendon (p. 35). Because oats (and other cereals) are poor in certain minerals, especially lime and chlorine, milk products such as separated milk are excellent supplements, especially for calves, pigs and poultry.

The whole grains ground to a fine meal are known as Sussex Ground Oats. Rolled oats are prepared by passing the grain, previously washed, dried and softened by steaming, between rollers in order to flatten them, after which they are dried. In the preparation of oatmeal for human consumption, the grain is submitted to a cleaning process to remove weed

[1] FAGAN, T. W., 1919, " Oats : their milling and by-products," *Scot. J. Agric.*, 11, p. 315

seeds, small stones, dirt, etc., and kiln dried prior to removal of the husk from the kernel by a shelling process. During shelling and grinding several by-products are produced, and they are incorporated in compound and other feeding cakes. The following percentage figures given by Fagan in the paper referred to above, represent the approximate yield of meal and by-products at a mill where careful records were kept—

Oatmeal	*Husks*	*Meal seeds*	*Scree dust*
59·7	17·4	4·5	4·5

Oat husks are rarely if ever fed alone to stock, but are finely ground for incorporating in compound cakes. They are used in breweries and distilleries to facilitate drainage of liquor from the mash, and hence may be present in brewers' and distillers' grains.

Meal seeds—husks with a varying amount of kernel attached—are produced from small grains which escape shelling, and are crushed and broken during the grinding process. Modern mills achieve more complete removal of the kernel, the proportion of which greatly affects the feeding value of the meal seeds.

Scree dust is obtained when, after shelling, the kernels and husks are submitted to a sieving process. It includes dust from the kernels and small particles of husk. A further product, oat dust, is obtained in a subsequent sieving process when some of the external tissues are removed from the kernel. The yield of oat dust is low and is included in the figure given above for scree dust. Unlike oat husks, meal seeds, scree dust and oat dust may be fed alone to pigs.

Barley contains much less fibre than oats, although in both cases the husk adheres to the grain, because the husk comprises only 10-11 per cent of the weight of the grain as compared with 20–30 per cent in oats. Barley meal, produced by grinding the whole grain, is the most highly esteemed carbohydrate-rich food for pig feeding. It may constitute 80 per cent of the ration in the final stages of fattening, and gives firm white bacon fat. Barley is also used for cattle, horses and sheep, but the highest quality grain is reserved for brewing when a number of useful by-products are obtained.

Malt culms or coombs consist of the dried sprouts, plumules and radicles separated from grain germinated for several days at about 15°C until shoots about an inch long are formed. Only good quality culms are used for feeding—poor grades are used as manures—and the amount should be restricted to not more than 4 lb for dairy cows as the culms swell considerably when moistened. They constitute a protein concentrate, and are used for incorporation in the balanced dairy concentrates sold as cubes.

About a third of the protein is in amide form, and the composition of the culms is very variable. Dark coloured culms, or a dusty product, should be rejected, but a good product is highly palatable and may be given to cattle, sheep and horses.

Brewers' and distillers' grains.—After separation of the culms from the germinated barley or malt by kiln-drying, the barley is steeped in water at about 60°C when the enzyme diastase converts starch into maltose, subsequently converted into alcohol by zymase in the added yeast. Consequently, most of the soluble carbohydrate is extracted leaving the " skins " or husks of the barley, the so-called brewers' grains. Distillers' grains are similar residues obtained from barley, maize, rye and rice used together with molasses and potatoes in distilling spirits such as whisky and gin. In the vicinity of the brewery or distillery, brewers' and distillers' grains are fed in the wet condition containing about 70 per cent of water, and are succulent foods which soon become sour and mouldy. Those not disposed of locally are dried, and have a nutritive ratio (Chapter 14) of about 4, compared with a wide ratio of 9 in the original grains, and are balanced for milk production. Distillers' grains are rather more concentrated than brewers' grains, and both are fed to cattle, horses and sheep. The wet grains are fed to dairy cows in quantities of 20–40lb daily and stimulate milk production. The dried grains may comprise about one third of the total concentrates of cattle, sheep and horses ; they are too fibrous for pigs.

Wheat is grown primarily for bread making, and only inferior grain is fed to stock. Unlike barley and oats, the kernel of wheat separates from the husk during threshing, and hence contains little fibre and more protein than the former. Wheat is highly esteemed as a food for poultry. Because of the paucity of fibre and high gluten content, wheat tends to assume a pasty condition in the mouth and stomach. It should be fed to cattle and sheep in the crushed form, and restricted to not more than about one quarter of the total concentrates. In larger amounts it causes digestive disturbances, and is therefore not such a " safe " food as barley and oats.

In the process of milling valuable by-products are produced, and a brief description of the wheat grain will help in explaining the nature of these substances. The greater part of the grain consists of the endosperm, largely made up of starch and gluten. This is surrounded by the aleurone layer made up of cells rich in protein and vitamins, and covered by the most fibrous portion of the grain, namely the skin or pericarp. One end of the grain is covered with fine hairs, and at the other end a depression on the convex side marks the position of the embryo or germ. The grain, separated from immature grain, weed seeds and gritty material, is washed, dried and passed through series of steel rollers which are set so that at first the grains are merely cracked to separate the germ from the starchy

endosperm, while progressively finer setting produces flour and milling offals.

In normal times about 70 per cent by weight of the grain is recovered as white flour, the aim being to include as much of the endosperm as possible and a minimum of bran and germ, for bran is rather fibrous, and germ oil tends to become rancid and would impair the keeping quality. During the war, and in subsequent years, the extraction was raised to 85 per cent, and resulted in bread containing a higher proportion of protein, fibre, minerals and vitamins of the B complex.

The milling offals or wheat feed are graded by sifting machines into bran and a number of products formerly described by a variety of names such as pollards, sharps, thirds, coarse middlings, fine middlings, toppings and parings, and subsequently grouped into two grades, weatings, and superfine weatings. In general, the by-products contain more fibre, oil, protein and ash than the starchy flour, or the original grain. Moreover, aleurone cells are detached with the bran which is, therefore, rich in vitamins of the B complex. The germ is usually incorporated with the offals and contains oil rich in vitamin E ; it is also made into wheat germ meal.

Bran is separated into coarse flakes or broad-bran, and straight-run bran containing more flour. Bran is a bulky food, has a stimulating action on the bowels, and is used as a laxative mash, while in the dry state it may have the reverse effect. It is palatable and an excellent food for cattle and horses, but neither should receive more than about 4 lb daily. Pregnant sows benefit from the inclusion of 10 per cent of bran in their rations. Although almost balanced for milk production, it is not very digestible, so that 5 to 6 lb are necessary per gallon of milk, compared with 3½ lb of balanced concentrates. It may also be fed to sheep and poultry.

Weatings and superfine weatings contain by law not more than 5·75 and 4·5 per cent of fibre respectively. They are highly digestible and palatable, have a higher energy value than bran, and are mainly used for feeding to pigs and poultry. Weatings, in particular the superfine grade, may be used to replace equal weights of cereals in livestock rations.

The term " weatings " was introduced in pre-war days, but, with the raising of the rate of extraction of flour from 70 to 85 per cent, it has been replaced by such terms as "fine wheat feed" (75 per cent extraction) and " fine and coarse millers' offals " (85 per cent extraction), the latter being produced after adding 10 per cent of barley before milling—see Bulletin No. 48 of the Ministry of Agriculture and Fisheries, " Rations for Livestock " by Dr. H. E. Woodman.

Maize is the most important imported carbohydrate-rich concentrate used for animal feeding, and contains more carbohydrates than any other

cereal. It has a wider nutritive ratio than wheat, barley and oats, and is a very poor source of calcium. The very low fibre content renders it liable to form a dough-like mass in the stomach. Its chief protein, zein, is deficient in tryptophan and hence of low biological value (p. 27). Maize is an excellent energy-giving food, but must be supplemented with foods rich in high quality protein and minerals, and containing enough fibre to prevent the formation of a dough-like mass. With these precautions it may be fed to all classes of farm animals, and 1 lb replaces about $1\frac{1}{4}$ lb of oats. The grain of different varieties varies in colour from white to yellow, orange and red, the yellow colour being due to cryptoxanthin a precursor of vitamin A absent in white maize.

Flaked maize, produced by passing steamed grain through rollers, is even more palatable and digestible than maize itself, and is used in the rations of dairy and fattening cattle, young horses, sheep and pigs. Other maize products include maize meal, maize germ meal or cake, and maize gluten feed. Meal produced by grinding the whole grain is a popular food, but tends to become rancid and unappetising during storage. In the preparation of cornflour and starch, the latter is separated from the husk, germ and gluten. Oil is extracted from the germ, which is then sold as cake or ground into meal containing about 10 per cent of oil. It is generally fed to dairy cows, but other farm animals may receive this very palatable food. Further separation of starch from degermed maize leaves bran and gluten. These are ground separately or, more generally, together, to produce maize gluten feed. This differs from the foregoing products in having a narrow nutritive ratio, in being balanced for milk production (but inadequate in biological value), and in being less palatable. It is fed to dairy cows and lactating ewes. Maize gluten meal contains still more protein, having the very narrow nutritive ratio of 2 as compared with 3 for maize gluten feed.

Rye.—As a grain crop rye is grown on poor light soils which fail to grow wheat, but is mainly grown as a forage crop for sheep and cattle. The grain closely resembles wheat in composition, but for reasons given above it must be fed with great care and generally in restricted amounts. Sheep may receive not more than $\frac{1}{2}$ lb daily, and cooked rye may comprise half the corn ration of horses. Rye may also be given to other farm animals, but is not highly esteemed as a foodstuff.

Other cereal products used to a limited extent include the grains and by-products of rice, dari, millet, tapioca and sago.

The protein-rich foods

The fundamental importance of protein in nutrition has already been emphasised and also the fact that the dry matter of young grass and forage

crops is an excellent source of high quality protein. Most of the foods grown in this country for winter feeding are much richer in carbohydrates than protein and, in order to make good this deficiency, large quantities of protein concentrates are imported in normal times. Several excellent foods of this nature can be grown on fertile soils in this country, and production is encouraged during periods of national emergency. In addition to home-produced and imported protein-concentrates, others comprise by-products from various sources.

Home grown leguminous seeds or pulses

Beans and peas, the chief members of this group, closely resemble one another in composition. Horse or field beans are very popular, but like the cereal grains are apt to cause digestive troubles when fed in the fresh condition, and must be used with great care. Beans from the previous season are preferable to new beans, as they may be used with complete safety and ground without becoming pasty, while the meal is less liable to heat during storage. Heated bean meal is very unpalatable and causes scouring. Mouldiness should be entirely absent, as decomposed bean protein has been known to prove fatal to horses.

Beans and peas are rich in carbohydrates and protein, but poor in oil and total ash. The ash is rich in phosphate and potash, but poor in lime and chloride, being rather similar to cereals in this respect. The protein is of excellent quality, and is of higher biological value than that of linseed cake for milk production owing to its high lysine content. Beans and peas stimulate milk production and are also highly favoured for other classes of stock.

Four pounds of a mixture of equal weights of bean meal and crushed oats provide sufficient nutrients for the production of a gallon of milk, and a crop consisting of a mixture of oats, beans and peas, grown to maturity and threshed, provides a most valuable concentrated food for winter feeding. The chemical composition and nutritive value will vary, of course, with the proportion of oats to beans and peas.

As a source of protein beans are excellent in the rations of fattening bullocks and pigs, while peas are more frequently used for sheep. Beans are particularly useful for horses doing very hard work, as they are sustaining and have a stimulating effect, and 2–4 lb may replace an equal weight of oats in order to increase the protein allowance for severe work. They should be cracked or kibbled for horses and cattle, and ground into meal for pigs and calves. Flaked beans are also produced to some extent and may excel over whole or ground beans.

Purchased bean meals are produced from a mixture of British and foreign beans and do not contain the Java bean, formerly used with fatal

results owing to the presence of a cyanogenetic glucoside phaseolunatin, which on hydrolysis yields glucose, acetone and hydrocyanic acid (p. 14).

Other leguminous seeds less frequently used are vetch seeds, lentils, gram and lupins.

Oil cakes and meals

These by-products, obtained in the extraction of vegetable oils from seeds and fruits, are of great importance as animal foods. The various seeds and fruits contain from 17·5 to 48·9 per cent of oil, which is used for such purposes as the manufacture of soap and margarine, extraction being accomplished by pressure and/or solvents. Where hydraulic pressure is used the residues contain 5–10 per cent of oil, while the " expeller " process leaves 4–8 per cent in the product. The seeds are crushed and heated in a steam " kettle " to 75–80°C prior to compression, and the residues are obtained as cakes, or as cubes, nuts and flakes in the expeller process. In the latter, pressure is exerted by means of a screw of varying pitch rotating in a horizontal cylinder, the oil escaping through the perforated sides. Solvent extraction with such liquids as benzine and petrol is more efficient, leaving only 1–2 per cent of oil, and the residues are heated by steam to expel the solvent. Heating facilitates extraction of the oil by pressure, improves the palatability of the residues, and destroys injurious substances possibly present in the seed, but overheating chars the product and impairs the flavour. Cakes and meals produced by solvent extraction are sold as " extracted " products.

Many seeds and fruits are covered with fibrous coatings, which may or may not be removed before extraction. In the former case " decorticated " cakes and meals are obtained, while those containing the fibrous coating are referred to as undecorticated products, and are less digestible and nutritious than the former.

In general, oil cakes and meals are fairly rich to very rich in protein, and contain variable amounts of oil and fibre. They contain much more ash than cereal grains and pulses, the ash being rich in phosphate and potash, and containing appreciably more lime than the former, but being equally poor in chlorine. Bulletin No. 48 of the Ministry of Agriculture and Fisheries gives the composition of some 40 oil cakes and meals, but only the more important types will be considered here. For further details the reader should consult " The use of oil cakes and extracted meals " by Dr. H. E. Woodman (Bulletin No. 11 of the Ministry of Agriculture and Fisheries. H.M. Sta. Office).

Linseed cake and meal.—Linseed cake is the most highly esteemed of these foods, due to long established use and several important properties.

It is laxative and has a tonic effect, which manifests itself in the healthy bloom imparted to the animal's coat and in the suppleness of the skin. It is used for fattening bullocks especially in the later stages and, because of its high palatability and digestibility, is greatly favoured for young ailing animals. Linseed cake meal is similar in feeding value, but extracted meal will be poor in oil. These foods are not used in large amounts because they cause butter and animal fat to assume an oily consistency.

Linseed, the seed of flax, is itself used to some extent for feeding to ailing animals, and as a butterfat substitute for calves receiving separated milk. Because of its very hard indigestible coat, it is soaked, cooked, crushed or ground, but linseed meal must not be confused with linseed cake meal. Linseed products must be prepared with great care for young calves, because they contain the cyanogenetic glucoside linamarin, which yields prussic acid on hydrolysis (p. 14). Boiling for 10 minutes renders linseed products safe for calves, whereas steeping in warm milk or water encourages hydrolysis, and the product may prove fatal due to the sudden escape of a lethal dose of HCN when the warm mash reaches the stomach. Although prussic acid may be detected in all samples of linseed, which contains on an average about 0·05 per cent, adult animals are rarely affected in this way, possibly because the poison is not a cumulative one, and is not produced in lethal amounts in the more usual methods of feeding.

Groundnut (*earth nut*) *cakes and meals* are the residues obtained from a leguminous nut, the ground or earth nut, also called peanuts and monkey nuts. Undecorticated, semi-decorticated and decorticated cakes and meals are produced as well as extracted meal. The difference in composition between the decorticated and undecorticated cake may serve to illustrate the important effect of removing the husk. While the former contains 46·8 per cent of protein and only 6·4 per cent of fibre, the undecorticated cake contains 30·2 per cent of protein and 22·9 per cent of fibre. The decorticated cake is a very safe food much used in the rations of dairy cows, fattening cattle and sheep ; undecorticated cake is mainly used for store cattle and low-yielding dairy cows. The former is also fed in limited amounts to pigs, but large amounts produce soft fat. For this reason extracted meals are generally preferable to those of higher oil content for pig feeding. Both the undecorticated and decorticated cakes may be fed to working horses, 2 lb of the latter replacing 4 lb of oats.

Palm-kernel cakes and meals.—The rather unpalatable and gritty nature of palm-kernel cake, together with a tendency to develop rancidity during storage, militated against its popularity when introduced into this country during the last century. Subsequently, it has been much used for "steaming up" (p. 140), and has grown in popularity. It should be

introduced very gradually into a ration, and its flavour may be improved by mixing with molasses or other more palatable foods. It is balanced for milk production, $3\frac{1}{2}$lb providing the energy and protein required to produce a gallon of milk, and it is chiefly used for this purpose. Fattening cattle, sheep, horses and pigs may also receive suitable amounts of the cake or meal, which must be strictly limited for pigs as excessive quantities cause scouring.

Coconut cake and meal are produced from the dried kernel or copra of the coconut. In feeding value they closely resemble palm-kernel cake and meal, and have a similar tendency to become rancid unless stored in a dry condition ; the rancid cake causes scouring and care should be taken to purchase cake in a sweet condition. Like palm-kernel cake it is balanced for milk production, and is not very palatable when first introduced into a ration. Both foods are reputed to increase the butter-fat content of milk, and coconut cake produces a firm butter of superior flavour to that obtained when linseed or cotton-seed cakes are fed, but not more than 4lb per head should be fed daily because the butter tends to become tallowy. Coconut cake and meal are also used for fattening cattle and pigs, and produce firm bacon fat. Part of the oat ration for horses may be replaced by an equal weight of coconut meal. Because coconut cake and meal swell when moistened they are soaked in water before feeding.

Cotton-seed cakes and meals.—Undecorticated cotton cakes are made from seed obtained from Egypt and Bombay. Both seeds contain cotton lint, which is rather difficult to remove from the Bombay seeds, and the cakes obtained contain more cotton fibres than those made from Egyptian seed, but are only little inferior in feeding value as the cotton fibres are very light. The undecorticated cakes are very fibrous, contain about 21 per cent of fibre, and are unsuitable for young stock. Their chief use is to counteract the laxative effect of luscious grass, or the heavy root rations fed to cattle or less frequently to sheep. For this purpose the cattle may have to be housed temporarily before they will eat the cake which is not very palatable. When the animals have become accustomed to the young grass, the cake should be replaced by carbohydrate foods. Decorticated cotton cake too is astringent (binding), but to a lesser degree. The decorticated cakes are of much higher feeding value and contain about 40 per cent of protein. They contain little cotton and husk, and are distinctly yellow in colour, while the undecorticated cakes are greenish brown and contain cotton fibres and black husks.

When fed in large quantities, cotton-seed products may have a poisonous effect due to the presence of gossypol a toxic phenolic compound $C_{30}H_{30}O_8$ whose mode of action is incompletely understood, but has been associated with vitamin A deficiency and a low level of nutrition. The trouble is

more common with young sheep, calves and pigs of all ages than with older cattle and sheep.

Dairy cows may receive 2–4 lb of cotton cake daily. It has a hardening effect on the butter-fat, and in larger quantities tends to impair the flavour and consistency. Fattening cattle may be given about twice as much, but for sheep the quantity should be restricted to not more than ½ lb. Cotton-seed products are unsuitable for poultry, and horses do better on other cakes.

Soya-bean cake and meal.—The soya-bean differs very greatly from beans grown in this country, for it contains a much higher protein content and about twelve times as much fat. The cake and meal resemble decorticated cotton-seed and groundnut cakes in containing over 40 per cent of protein, and when first introduced into this country, the troubles arising from their use were due to the feeding of excessive amounts. In moderation they are perfectly safe, highly palatable and nutritious foods. Dairy and fattening cattle may receive about 2 lb per day, and smaller quantities may be given to all classes of farm stock. The extracted meal is an excellent substitute for fish meal in rations for pigs, but must be supplemented with minerals, as it is poor in lime and chlorine, and although rich in phosphate, is not as rich as fish meal. Soya-bean products are laxative, and are used together with undecorticated cotton-seed cake for fattening animals, since this cake has astringent properties. Soycot cake is actually a mixture of the two cakes now used for dairy and fattening cattle.

Other oil-cakes include less well-known products made from the seeds of sesame, sunflower, safflower and rape. Rape cake sometimes contains a mustard oil glucoside sinigrin derived from black mustard seeds (p. 14). The cake has a bitter flavour, is not fed to young stock and to a limited extent only to older animals. It is apt to taint milk, which, when so affected, should never be given to children, and is used to some extent in compound cakes, inferior grades being used as a manure.

Compound cakes and meals are mainly protein concentrates made of a variety of foods mixed in such a way as to meet particular needs such as milk production, calf rearing, fattening and egg production. They are sold in the form of cakes, cubes, nuts and meals, and may be fortified with minerals and vitamins. Dried grass, clover and lucerne meals rich in minerals and carotene may be used for this purpose. Molasses and locust beans are usually incorporated to increase the palatability, and spices such as aniseed, fenugreek, fennel and dill are added with the same object, although heavy spicing is unnecessary where wholesome ingredients have been used. Molasses also serves to bind the rather friable constituents together.

During the war, and in subsequent years, imported concentrated foods such as oil-cakes and meals and maize products have been in short supply. At present, farmers are able to buy only very limited amounts of the individual foods, as they are still used to prepare "national compounds" balanced for various purposes such as milk production, rearing, pig feeding, and poultry feeding.

Foods of animal origin

These fall into three main groups, namely, residues from the meat industry, fish residues, and milk products. Preparation of meat and bone products involves heating to 100°C or more for at least one hour in order to comply with the Foot-and-Mouth (Boiling of Foodstuffs) Order, 1932, or under certain exemptions to a maximum of 72°C. The heating removes moisture and part of the fat, and solvent extraction is also used. The products obtained at the lower temperatures have the higher feeding value.

Meat meal is made from carcass residues from slaughter houses and meat factories, and from meat unfit for human consumption. The meal varies greatly in composition, contains some 40 to 70 per cent of protein and less than 3 to over 15 per cent of fat, depending upon the method of preparation. It is a very rich source of high quality protein, and is used in small quantities supplemented with minerals such as steamed bone flour. Meals of low fat content keep better than fatty meals which may develop rancidity.

Meat and bone meal contains ground bones as well as the dried meat, and is an excellent source of protein and minerals, chiefly calcium phosphate, for pigs, poultry and growing animals. It contains up to 50 per cent of protein and about 10 per cent of both CaO and P_2O_5.

Steamed bone flour is prepared from bones which have been sterilised and freed from fat and gelatin. It contains approximately 46 per cent of CaO, 31 per cent P_2O_5 and is used as a mineral supplement, in many mineral licks, and in proprietary compound cakes and meals.

Dried blood contains up to 80 per cent of protein of very high quality, but is poor in minerals. It is used as a protein supplement for young stock, pigs and poultry, but requires to be supplemented with minerals.

Fish meal is made in two grades from fish residues. White fish meal from low-oil residues of plaice, haddock and halibut, contains not more than 6 per cent of oil and 4 per cent of salt, and is a very valuable source of proteins and minerals. Because of its comparatively low oil content, it is much less prone to taint milk and animal fat than the second grade of meal. This is made from mackerel and herrings, contains 10–15 per cent of oil, and is liable to cause taints. The comparatively high content of salt may have an adverse effect on animal health. Because of the high

protein content and the possibility of taints in the produce, it is well to restrict fish meals to not more than 10 per cent of rations. White fish meal is used for young stock, pigs and poultry, the poor grade meal for purposes where the development of taints is immaterial, for store and beef cattle, young horses and calves. Fish meals are especially valuable as protein and mineral supplements for cereal foods.

Meat and blood meals are also fed in restricted amounts, the former at the rate of about 5–10 per cent and the latter about 2 per cent of the ration. Inferior grades of meat and bone, blood and fish meals are used as manures.

Milk products are used to a limited extent in stock feeding, and are produced by drying skimmed or separated milk, buttermilk and whey. Since milk itself contains all the constituents necessary for healthy growth (see p. 138), it is not surprising that the feeding value of these products is high. Dried skimmed, separated milk and buttermilk contain almost the whole of the protein, lactose and ash of the original milk, and are excellent sources of high quality protein and minerals. Dried separated milk contains over 30 per cent of protein, about 47 per cent of lactose and nearly 8 per cent of soluble minerals rich in lime, phosphate, potash and chlorine ; moreover, it is very palatable and highly digestible. The high cost of this food, and its suitability for human consumption, militates against its general use for stock, but it is used in mixtures for poultry, and for calves with a butter-fat substitute. Dried buttermilk is somewhat richer in protein and poorer in lactose, and is very useful for poultry feeding. Where available, the liquid products are, of course, used for calves, pigs and poultry.

In cheese-making, protein as well as fat is removed from the milk, and dried whey is a carbohydrate-rich concentrate. It contains about 70 per cent of lactose and 12 per cent of protein largely lactalbumin, with about 8 per cent of minerals. It is used for calves, young pigs and poultry.

Miscellaneous feeding stuffs

In addition to those already described, there are several foods which may provide useful supplements in certain circumstances, and especially in times of national emergency when many of the foods described are unobtainable or in short supply.

Acorns have been widely used for pig feeding and constitute a carbohydrate-rich food. They may also be given to sheep and poultry, but are unsuitable for cattle, especially those under two years old, and have been responsible for many fatalities. They may be fed whole to pigs, or after drying and grinding into meal, about 3 lb of fresh acorns or 2 lb of meal daily being suitable amounts. Sheep receive small amounts, about ½ lb

of meal daily, and poultry about 1 oz. As acorns are binding in action they should be fed along with succulent or other laxative foods.

Yeast.—Dried yeast contains about 48 per cent of protein, is rich in carbohydrates, minerals, and vitamins of the B-complex, but poor in oil. It is chiefly fed to pigs and poultry, and may constitute up to 10 per cent of the ration. The bitter taste renders it unpalatable to dairy cows at first, but they become accustomed to it and consume it readily. In the vicinity of breweries yeast is fed in the wet condition, and should first be heated until it boils to kill it and prevent digestive disturbances.

Swill consists of waste human foods such as peelings, scraps of meal and vegetables, and is very variable in composition. It must be boiled for at least one hour before feeding (Foot-and-Mouth Disease (Boiling of Animal Foodstuffs) Order 1932), and may be processed into " pudding " or dried. Excess fat is skimmed off during the boiling or steaming process to avoid indigestion and excessively fat carcases of poor quality. Swill is fed chiefly to pigs and also to poultry, and constitutes a valuable food.

Miscellaneous foods include apples and their pomace or residues from cider-making, horse chestnuts, beech mast, bracken, gorse, nettles and many others described in " Substitute Feeding Stuffs," Growmore Bulletin No. 8 of the Ministry of Agriculture and Fisheries.

CHAPTER 12

FEEDING STANDARDS

(1) STARCH EQUIVALENTS

It was the growing importance of stall feeding, accompanied by the increasing variety of foods coming into general use, that gave rise to the desire for a method of comparing the feeding value of animal foods. Among the first to make the attempt was Thaer who, with the collaboration of the chemist Einhof, prepared tables giving the " hay equivalents " of foods. Their figures were an attempt to give the weight of a food which would produce the same increase in weight of an animal as 100lb of meadow hay, and were obtained by feeding experiments and also by extracting hay and the foods under comparison with dilute aqueous solutions of acids and alkalies.

The method suffered from several weaknesses. Hay is far too variable in composition to be a satisfactory standard, and measurements of live-weight are fraught with inaccuracies. Nevertheless, Thaer's hay equivalents were used for many years and, although his results could have no permanent value, they represented an important stage in the attempt to compare the nutritive value of foods.

During this time, chemical analysis was being applied to feeding stuffs, and a distinction had been made between the nitrogenous and non-nitrogenous constituents. This led to further advances, namely, the table of " hay equivalents " based on nitrogen content published in 1836 by Boussingault, and Grouven's feeding standards based on the total protein, fat and carbohydrates in 1859. Meanwhile, German workers had been engaged in determining the digestibility of foods and, as a result of this work, Wolff made the first attempt to use digestible nutrients to formulate the requirements of farm animals. His figures, published in 1864, were revised annually up to 1896, and afterwards up to 1906 by Lehmann.

The comparative slaughter method

In our own country important work was being carried out at Rothamsted, where, towards the end of the nineteenth century, Lawes and Gilbert had elaborated their comparative slaughter method to determine how the amount of animal carcass formed was related to the food consumed, and from what source fat was obtained. They selected a group of animals of the same breed and sex, closely resembling each other in age, weight and general condition ; some of these were slaughtered

and the carcasses weighed, sampled and analysed. In this way they determined the weights of bone, fat, flesh, and also protein, fat and ash constituents contained in the animal carcasses, and assumed that those of the unslaughtered animals were similarly constituted. These animals were fed on given quantities of foods of known composition, so that, when their carcasses were weighed and analysed, it was possible to relate the quantities of carcass, bone, protein, fat and ash formed to the food consumed. One of the most important facts to emerge from their work was that the carbohydrate of the food was the chief source of body fat. They also showed that a young animal retained up to 25 per cent of the protein fed, whereas fattening animals retained only about 5 per cent. While the directness of the comparative slaughter method had its obvious merits, it was extremely laborious and expensive and was abandoned for many years. Subsequently, it has been used in this country and in America to investigate specific problems, including certain disputed points relating to the winter fattening of cattle, the value of protein from different sources for the formation of protein tissues, and the amount and quality of dressed carcass produced by feeding given rations.

The balance method

Less direct, but extremely valuable methods of studying the relative nutritive value of the various food constituents, and hence of foods themselves, were being worked out in Germany, where the method known as the " balance method " was being developed. This method was a great advance on previous methods, for it obviated the need for slaughtering animals or assuming similarity in the carcasses of two groups of animals, weaknesses inherent in the comparative slaughter method. It was also completely free from the inaccuracies of live-weight measurements. The balance method was perfected by Kellner, whose success was such that the system of rationing employed in Britain and other European countries is based almost completely on his results.

Kellner's method was to feed a steer on a ration of known weight and chemical composition in a specially constructed room known as a respiration chamber. Provision was made for collecting the solid, liquid and gaseous products of excretion each of which was subjected to chemical examination. The animal wore a light harness to which a bag was attached for collecting the solid excreta, while the urine passed into a funnel connected to a bottle by means of rubber tubing. The chamber was fitted with an inlet tube for entry of air, and an outlet through which all gaseous products of metabolism passed. Moisture and carbon dioxide present in the air entering and leaving the chamber were absorbed, e.g., the former in concentrated sulphuric acid and the latter in soda lime, and

methane—formed by bacterial digestion of cellulose—was similarly absorbed after oxidation to carbon dioxide and water. The great care taken by Kellner in his most accurate experiments is illustrated by the fact that even scurf was brushed from the animal and retained for analysis. From the total weight of solid, liquid and gaseous excretory products, and the data obtained from their analysis, Kellner was able to compare the total amounts of carbon and nitrogen voided with the total amounts present in the food consumed, which was weighed and analysed.

When the steer had become accustomed to its surroundings and was consuming its ration normally, the experiment proper was begun, and it was possible to adjust the ration so that the animal neither retained carbon or nitrogen from the food, nor lost either element by drawing upon body reserves of fat or protein. Kellner thus had the animal under complete control, and the state of carbon and nitrogen equilibrium attained is well illustrated by the following simplified example giving average daily figures.[1]

Balance experiment with a steer weighing 1,000 lb

Ration : 14 lb per day of meadow hay

Carbon Balance		*Nitrogen Balance*	
14 lb hay contained ...	5·2 lb C	14 lb hay contained ...	0·22 lb N
Excreta contained—		Excreta contained—	
Dung...	0·80 lb C	Dung	0·10 lb N
Urine	0·08 ,,	Urine	0·12 ,,
Breath	4·11 ,,	Breath	—
Marsh gas	0·21 ,,	Marsh gas	—
	5·2 lb C		0·22 lb N

In other words the animal was on what is called a "maintenance ration," that is, one which served to keep it alive and maintain all its bodily functions without either gaining or losing fat or flesh.

Kellner's next step was to add a known weight of pure starch to this maintenance ration and, after the animal had been kept on the ration for the necessary experimental period, he again drew up a similar balance sheet of the carbon and nitrogen consumed and excreted. Actually 1 lb of starch fed caused the animal to retain 0·19 lb of carbon, while the nitrogen remained in equilibrium. Thus, the carbon went to form fat,

[1] Wood, T. B., 1927, "Animal Nutrition," p. 120 (University Tutorial Press Ltd., London)

and since fat contains 77 per cent of carbon, the feeding of 1 lb of starch enabled the formation of $0{\cdot}19 \times 100 \div 77 = 0{\cdot}25$ lb of fat. Similar experiments were carried out by adding pure fat or protein to a maintenance ration, and from the average results obtained he was able to calculate the weight of fat formed from 1 lb of the various food constituents. His results may be summarised thus(2)—

1 lb of digestible protein consumed	enabled	the	formation	of	0·235 lb	fat
1 lb of digestible fat in coarse fodders	,,	,,	,,	,,	0·474 lb	,,
1 lb of digestible fat in cereals	,,	,,	,,	,,	0·525 lb	,,
1 lb of digestible fat in oil seeds	,,	,,	,,	,,	0·598 lb	,,
1 lb of digestible carbohydrates	,,	,,	,,	,,	0·248 lb	,,

The figures show that the fat varied in nutritive value with the source from which it was obtained, and to understand this it is necessary to consider the method generally adopted to determine this constituent in a feeding stuff. A known weight is extracted with ether (nowadays petroleum spirit B.P. 40–60°C is used), and the total extract dried and weighed. It is not difficult to realise that the purity of the " fat " extracted will vary considerably from one type of food to another, for non-fatty substances of unknown feeding value are included in this fraction, e.g., waxes, essential oils, colouring matter such as chlorophyll, and organic acids. Thus, while the " ether extract " as it is more correctly called, is composed of relatively pure fat in the case of oil seeds, more non-fatty substances are extracted from cereals, and the fat obtained from coarse fodders is very impure, and consequently of greatly reduced feeding value compared with pure fat.

Kellner was now in possession of two very useful sets of data relating to the nutritive value of foods. His digestibility experiments enabled him to calculate the percentage of digestible protein, fat, soluble carbohydrates and fibre present in a feeding stuff and, from his balance experiments, he could calculate the weight of fat produced by one pound of each of these constituents. Kellner now put his knowledge to a practical test. He first of all estimated the amount of fat which a feeding stuff of known composition could be expected to produce. The procedure may be illustrated by reference to some typical foods. Palm-kernel cake contains the following percentages of digestible constituents : protein 16·4, oil 5·3, soluble carbohydrates 39·4 and fibre 5·1. If these percentages are multiplied by the figures giving the weights of fat produced by 1 lb of the

[2]KELLNER, O., 1926, " The scientific feeding of animals," (translated by W. Goodwin), pp. 35–70 (Duckworth, London)

respective constituents, it is found that 100lb of palm-kernel cake may be expected to produce in the animal body 18·1 lb of fat, thus—

$$\left.\begin{array}{r} 16{\cdot}4\times0{\cdot}235=3{\cdot}854 \\ 5{\cdot}3\times0{\cdot}598=3{\cdot}169 \\ 39{\cdot}4\times0{\cdot}248=9{\cdot}771 \\ 5{\cdot}1\times0{\cdot}248=1{\cdot}265 \end{array}\right\}\text{Total}=18{\cdot}1$$

It will be noted that since this food comes into the category of an oil seed, the fat is relatively pure and the factor 0·598 is used.

Considering another food, good meadow hay, the percentages of digestible nutrients are on an average: protein 3·8, oil 1·0, soluble carbohydrates 25·7, fibre 15·0. Thus 100lb may be expected to yield $(3{\cdot}8\times0{\cdot}235=0{\cdot}893)+(1{\cdot}0\times0{\cdot}474=0{\cdot}474)+(25{\cdot}7\times0{\cdot}248=6{\cdot}374)+(15{\cdot}0\times0{\cdot}248=3{\cdot}720)$ or 11·5lb fat.

Proceeding in this way Kellner calculated the theoretical fat-producing values of a number of foods, and then tested his results by means of balance experiments, that is, after adjusting the basal ration to maintenance—when no carbon or nitrogen was being retained or lost from the body—a given weight of a particular food was added, and from the carbon and nitrogen balance measurements he determined the quantity of fat actually formed. At least two important facts emerged out of the data obtained. He found that the weight of fat synthesised in the animal body was generally less than that calculated in the above manner. Secondly, while there was close agreement between the theoretical and actual fat-producing values of concentrated foods, wide divergences were obtained with fibrous foods or roughages. Ultimately it became obvious that the divergences were correlated with the fibre content of such foods, and Kellner attributed this to the extra work performed by the animal in digesting the crude fibre. He was able to confirm the depressing effect which fibre exerted on the digestibility of food constituents, by showing that very fibrous substances like millet husks and sawdust, not only had a negative feeding value, but actually depressed the value of other foods consumed (despite the fact that the millet husks contained appreciable amounts of digestible nutrients). By means of these and additional experiments Kellner succeeded in relating the actual fat-producing capacity of a food to its fibre content, and on this basis assigned a " value or V-number " to each food, representing the actual fat-producing capacity as a percentage of the calculated figure.

Such V-numbers are extensively used, and may be found in Table 1 of the Appendix and in Bulletin No. 48 of the Ministry of Agriculture and Fisheries. In many cases, e.g., potato products, dried yeast and flaked

maize, V=100, and the following selection may serve to illustrate the wide variation from one type of feeding stuff to another—

Grains and seeds (including oil-seeds)	V=92–100
Oil cakes and meals	V=84–100
Roots	V=70–100
Grasses and green legumes..	V=76– 95
Hay	V=59– 93
Straws	V=18– 55

The value number for each type of food is greatly influenced by its quality and condition, as in the above examples where poor and very good meadow hay have values of 59 and 93 respectively, and the very tough red clover straw has a value of 18, whereas the V-numbers for cereal straws approximate to 50.

Starch equivalents

Using his value numbers Kellner calculated the actual fat-producing power of about 300 different foods, but instead of expressing his results in terms of the amount of fat produced by feeding 100 lb of the food, he introduced the term " Starch Equivalent ", which gave the number of pounds of starch necessary to produce the same amount of fat as 100 lb of the food. Again, an example will serve to illustrate the meaning of this term. It was shown on p. 108 that 100 lb of palm-kernel cake could be expected to produce 18·1 lb of fat, and from tables we find that for this food V=100. Hence 100 lb will actually produce 18·1 lb fat, and the starch equivalent of palm-kernel cake will be the amount of starch necessary to produce 18·1 lb fat. Since we know that 0·248 lb of fat is produced by 1 lb of starch, 18·1 lb fat will be produced by 18·1÷0·248 =73·0 lb.

While this example serves to illustrate what is meant by the term starch equivalent, in practice Kellner's factors for the production of fat are first converted into starch equivalents by dividing them by 0·248, the actual weight of fat formed by 1 lb of starch—

1 lb digestible protein consumed formed 0·235 lb fat = 0·235÷0·248=0·95 lb starch equivalent.

1 lb digestible fat (in coarse fodders) formed 0·474 lb fat = 0·474÷0·248=1·91 lb starch equivalent.

1 lb digestible fat (in cereals) formed 0·525 lb fat = 0·525÷0·248=2·12 lb. starch equivalent.

1 lb digestible fat (in oil seeds) formed 0·598 lb fat = 0·598÷0·248=2·41 lb. starch equivalent.

1 lb digestible carbohydrate formed 0·248 lb fat = 0·248÷0·248=1·00 lb. starch equivalent.

The starch equivalent of a food can now be obtained by multiplying the percentages of digestible nutrients by the appropriate factors, and the sum of the results by the V-number. Referring once again to palm-kernel cake, instead of calculating the theoretical fat-producing value of 100lb of cake, the theoretical starch equivalent may be calculated by using the above factors. Since V=100 for this food, the result will be the actual starch equivalent—

Digestible nutrients (per cent)			*Factors*		*Theoretical and actual starch equivalent (V=100)*
Protein	16·4	×	0·95	=	15·58
Oil	5·3	×	2·41	=	12·77
Soluble carbohydrate	39·4	×	1·00	=	39·40
Fibre	5·1	×	1·00	=	5·10
			Starch equivalent	=	72·9

By using the correct factors and V-numbers the starch equivalents of other foods are similarly calculated. However, in the case of hay, straw and fodders generally, it was considered preferable to adopt a somewhat different procedure in allowing for the effect of the crude fibre. Instead of employing V-numbers, a given amount is deducted for each 1 per cent of total fibre present in the food. The amounts deducted vary with the nature of the food and total fibre content ; the figures recommended by Kellner are given below([3])—

Fodder	*Deduction made for each per cent of crude fibre*
Chaffed hay and straw	0·29
Hay and straw in long condition	0·58
Green fodders containing :—	
More than 16 per cent of crude fibre	0·58
14 ,, ,, ,, ,, ...	0·53
12 ,, ,, ,, ,, ...	0·48
10 ,, ,, ,, ,, ...	0·43
8 ,, ,, ,, ,, ...	0·38
6 ,, ,, ,, ,, ...	0·34
4 ,, ,, ,, ,, ...	0·29

The manner in which the deductions are made may be illustrated by referring again to good meadow hay (p. 108), and using the appropriate factors—

[3]Kellner, O., 1926, " The scientific feeding of animals," (translated by W. Goodwin), p. 281 (Duckworth, London)

Digestible nutrients (per cent)			*Factors*		*Starch equivalent*
Protein	3·8	×	0·95	=	3·61
Oil	1·0	×	1·91	=	1·91
Soluble carbohydrates	25·7	×	1·00	=	25·70
Fibre	15·0	×	1·00	=	15·00
					46·22
Total fibre content=26·3 per cent, deduct			0·58×26·3	=	15·25
			Starch equivalent*	=	31·0

Considering another example, the starch equivalent of closely grazed pasture grass containing 2·6 per cent of crude fibre is calculated as follows—

Digestible nutrients (per cent)			*Factors*		*Starch equivalent*
Protein	3·8	×	0·95	=	3·61
Oil	0·7	×	1·91	=	1·34
Soluble carbohydrates	7·8	×	1·00	=	7·80
Fibre	2·1	×	1·00	=	2·10
					14·85
			Deduct 0·29×2·6	=	0·75
			Starch equivalent	=	14·1

The starch equivalent system has several advantages as a means of expressing the nutritive value of foods, for it represents this in a single figure and, moreover, a net figure; that is, it gives the actual fat-producing value of a food. It is thus comparatively easy to assess the relative values of feeding stuffs and, as will be shown later, to make use of them in compounding rations for farm animals.

The position is not quite as simple as this, however, for when one considers the very different functions of fats and carbohydrates on the one hand, and proteins on the other, it is not surprising that special attention has to be paid to the latter in compounding rations. A given starch equivalent gives no information regarding the protein content of a food, and the protein requirements of an animal have to be considered independently. This is not a serious disadvantage, for, as will be seen later (Chapter 15), a simple adjustment only is necessary.

*The starch equivalent values of hay calculated in the above manner are lower than those quoted in the Appendix from Bulletin No. 48 of the Ministry of Agriculture and Fisheries where they have been increased by one fifth to bring them into line with American work.

Despite the advantages of the system, it is important to realise that Kellner's work was concerned mainly with bullocks in store condition, that is, making slow growth without putting on fat, and his starch equivalents refer to the value of foods for fattening such animals. Subsequently they have been used, rather indiscriminately perhaps, not only for fattening but for growth, milk production and work and, moreover, for non-ruminants as well as ruminant animals. In this connection it is well known that different classes of animals vary in their ability to utilise certain food constituents. Thus, starch is used more economically by the pig than by ruminants due to the destructive action of rumen bacteria, which, on the other hand, enable ruminants to digest and assimilate fibrous foods much more efficiently than non-ruminants. For this reason the starch equivalents of roughages can have little significance in the case of pigs, horses and poultry.

Finally, the reader must be warned against regarding the value as an absolutely rigid quantity, for although Kellner calculated starch equivalents for some 300 foods, owing to the complexity of the measurements, these results were based on comparatively few actual determinations. Furthermore, any one food is subject to great variation in composition, due to such influences as season, soil and stage of maturity. Nevertheless, starch equivalents have been used with considerable success, and form the basis of the system of rationing in Britain and other European countries. Before proceeding to describe the main principles of this system, two further types of feeding standards will be described briefly, namely, those used in America and Scandinavia.

CHAPTER 13

FEEDING STANDARDS

(2) AMERICAN AND SCANDINAVIAN STANDARDS

The gross energy value of foods

BRIEF reference has already been made in the Introduction to the organic portion of a food as that which burns away when the food is ignited. If the ignition is carried out in a calorimeter, it is possible to determine the total or gross energy value of the food in terms of calories, a calorie being the amount of heat required to raise the temperature of one gram of water by 1°C. Larger quantities of heat may be expressed in terms of the large Calorie (=1000 calories) or therm (=1000 Calories). In practice a bomb calorimeter is used. The " bomb " is a flask-shaped structure made of stout metal such as stainless steel the top of which may be screwed down tightly. Two rods, suitably insulated, pass through the top of the bomb and function as terminals. To the lower end of one a platinum crucible is attached, and also a thin fuse wire which dips into the crucible and makes contact with the other terminal. A weighed amount of food is placed in the crucible, and oxygen is pumped into the bomb at a pressure of 20–30 atmospheres. When the terminals are connected to a source of electric current, the fuse wire becomes hot enough to ignite the food, and the heat passes into the water surrounding the bomb. The gross energy value of the food in calories is obtained by multiplying the rise in temperature of the water (measured to 0·001°C), by the sum of the water equivalent of the bomb and the weight of water in grams. Certain corrections have to be applied, for example, for the electrical energy used to heat the wire, for heat generated by oxidation of the wire, and for acids formed by oxidation of such elements as nitrogen and sulphur.

Metabolisable and net energy

In America Armsby and his successors working at the Institute of Animal Nutrition of the Pennsylvania State College, set out to determine the energy value of foods. Although they used methods quite different from those of Kellner, their aims were similar, namely, the expression of nutritive value as a net figure.

It will be obvious that only a portion of the gross energy can be available to the animal, for the indigestible solid excrement still has considerable energy value. This is also true of the methane produced by bacterial

decomposition of cellulose, and of certain products of metabolism such as urea, uric and hippuric acids excreted in the urine. By collecting and weighing the total excrements, and burning representative samples of each in a bomb calorimeter, the total energy value of the excrements was calculated and, when this was subtracted from the gross energy value of the food, the quantity theoretically available to the animal was obtained. This was called the " metabolisable energy " of the food, and corresponds with the theoretical fat-producing value calculated by Kellner. It is sometimes expressed in terms of starch as the maintenance starch equivalent, and must not be confused with Kellner's values which are production starch equivalents. When allowance is made for the energy value of the solid, liquid and gaseous excrements, it is found that carbohydrates, proteins and fats have metabolisable energies of 1,707, 2,133 and 4,000 Calories per pound respectively. Taking starch as unity, the relative values are 1, 1·25 and 2·3, and the metabolisable energy of a food, e.g., barley, may be expressed in therms or as maintenance starch equivalent as follows—

	Calories	*Pounds Starch*
Digestible carbohydrates+fibre	63·4×1,707=108,224	63·4×1·0 =63·4
Digestible fat	1·2×4,000= 4,800	1·2×2·3 = 2·8
Digestible protein ...	7·0×2,133= 14,931	7·0×1·25= 8·8
Metabolisable energy per 100lb	=127,955	75·0
	=128·0 therms	

Thus, 100lb of barley have a metabolisable energy of 128·0 therms, and are equivalent to 75·0lb of starch for heat production.

Just as Kellner set out to test his theoretical fat-producing values by means of his respiration chamber, so Armsby adapted the animal calorimeter in order to find whether the whole of the metabolisable energy could be accounted for. This was necessary in order to show that the energy relationships in the animal body conformed with the laws of physics and chemistry. Armsby's calorimeter consisted of a chamber large enough to accommodate a steer comfortably. In order to prevent loss of heat it was fitted with double walls and, by means of a thermostatic device, the outer and inner walls were maintained at the same temperature. A constant flow of water was maintained through the calorimeter by means of a system of pipes and, by measuring the amount of water and the differences in temperature of that entering and leaving, the heat generated by the animal's body was calculated. This was not the total amount produced, for the air leaving the chamber was naturally warmer

than the inlet air, and the heat consumed in this way was calculated as being equal to—

Difference in temperature of inlet and exit air × Total volume of air × Density of air × Specific heat of air

In addition, heat was used to vaporise the moisture present in the animal's breath, and was accounted for by weighing the water removed in this way, and multiplying the weight by the latent heat of vaporisation of water. Armsby was able to show that the total heat evolved by the animal was equal to the metabolisable energy of a food when the animal was neither gaining nor losing fat or protein. It is extremely difficult to secure such conditions in practice, for carbon and nitrogen are either being retained in or lost from the body by synthesis or breakdown of fat and protein. Since the building up of body tissue is tantamount to the retention of energy, whereas heat is evolved in the reverse process, it was necessary for Armsby to carry out carbon and nitrogen balance determinations in order to draw up a complete balance of energy. With this aim in view he designed his calorimeter as a respiration chamber, and the following summary of the results of a typical determination will serve to illustrate the essential principles of his method.[1]

A steer consumed 6,988g timothy hay and 400g linseed meal having a metabolisable energy of	12,101	Calories
Total heat evolved by the animal and measured in the calorimeter	11,493	,,
Heat stored as protein (amount calculated from weight of N retained)	380	,,
Heat stored as fat (amount calculated from the weight of carbon retained)	144	,,
Total heat accounted for	12,017	Calories

When one considers the very great complexity of the measurements involved, the agreement (within 0·7 per cent) between the theoretical or metabolisable energy and that actually accounted for is remarkably good. Together with general determinations of a similar nature it showed that, for all practical purposes, it was possible to account for the whole of the metabolisable energy of the food.

The next step was to determine whether the whole of the metabolisable energy was available for productive purposes, e.g., for fat production.

[1]Wood, T. B., 1927, "Animal Nutrition," p. 143 (University Tutorial Press Ltd., London)

In testing his theoretical fat-producing values, Kellner had found that the amount produced was usually less than the calculated figure, and he attributed this to the energy consumed in digesting the fibre of the food. Rubner and many other workers have shown that immediately after a meal there is a marked increase in body metabolism—as shown by increased production of heat and CO_2 exhaled—and that the food constituents, particularly proteins, exert a stimulating effect on the energy exchanges of the body. This action is called " Specific Dynamic Action," and results in expenditure of a part of the metabolisable energy, for the heat evolved in this way is obviously not available for productive purposes, although some of it, at least, may serve to maintain body temperature.

The Pennsylvanian workers obtained results similar to those of Kellner, for the actual energy values of feeding stuffs were generally lower than the metabolisable energy. In order to determine the actual or " net energy " values, an ingenious modification of Armsby's original technique enabled them to dispense with the necessity of carrying out determinations of the carbon and nitrogen balance. A steer was fed on a ration insufficient to maintain its bodily functions, and the energy given out by the animal measured. Under these conditions the animal had to oxidise some of its reserve fat in order to maintain itself. The ration was now increased, but still kept below the maintenance requirements, and the heat evolved again measured. The result of this supplementary amount of food was that the animal had to utilise less of its reserve fat, and the difference in the quantity of energy obtained by the oxidation of body fat, when the first and second rations were fed, was equal to the actual or net energy value of this increased quantity of food. Again this can best be illustrated by giving an example.(²)

A steer received 6·17 lb timothy hay. The metabolisable energy of this was 935 Calories per pound, so that the metabolisable energy supplied was 935 × 6·17 =	5,768 Calories
Heat produced by the animal as measured by the calorimeter was	8,064 ,,
Therefore heat provided by oxidation of body fat ...	2,296 ,,

By increasing the ration to 10·21 lb hay, the metabolisable energy provided was 935 × 10·21 =	9,544 Calories
Heat produced by the animal as measured by the calorimeter =	9,812 ,,
Therefore heat provided by oxidation of body fat... ... =	268 ,,

[2] Wood, T. B., 1927, "Animal Nutrition," pp. 145–146 (University Tutorial Press Ltd., London)

Thus, 10·21—6·17 or 4·04lb timothy hay enabled the animal to conserve 2,296—268 or 2,028 Calories, which was the net energy value of the food. In other words, the metabolisable energy of the food was 935 Calories per pound, the net energy 2,028÷4·04 or 502 Calories per pound, and the difference, 935—502 or 433 Calories, the so-called " heat increment " was employed in the work of digestion and in specific dynamic action.

It was found that just as the divergence between Kellner's theoretical and actual fat-producing values increased with the fibre content, so the differences between the metabolisable and net energy values were greatest with fibrous foods. It is, in fact, possible for the energy expended in digestion to exceed the metabolisable energy of certain substances, which, therefore, have negative net energy values. This is true of such substances as sawdust and peat, and of wheat straw in the case of the horse.

Like Kellner's starch equivalents, Armsby's net energy values expressed the value of foods in a single net figure. Armsby assumed that none of the " heat increment " could be used by the animal, whereas, as mentioned previously, it is probable that a considerable amount may be used to maintain body temperatures, especially in cold climates ; from this point of view net energy tends to underestimate the value of roughages for maintenance purposes.

One of the criticisms applied to starch equivalents may also be levelled at net energy values, namely, that in both cases values worked out for a large number of feeding stuffs are based on comparatively few experimental determinations.

Metabolisable and net energy values are both subject to considerable variation. The values for a given food depend to some extent on the nature of other foods incorporated in a ration, also on the level of intake of the feeding stuff ; the net energy of corn grain and alfalfa decreased when the amount fed was increased from a liberal to a more liberal quantity. Moreover, the net energy of a food was not the same for various productive purposes, a given metabolisable energy having a lower net energy for fattening than for milk production. In view of these facts, American workers have become rather dissatisfied with net energy as a basis of rationing, and some have abandoned its use in favour of metabolisable energy and total digestible nutrients (T.D.N.=% Digestible (protein+carbohydrate+fat×2·25)).

It has already been pointed out (p. 111) that, when using starch equivalents, it is necessary to consider the protein requirements of an animal separately. This applies equally to net energy, and it is also worth mentioning that neither standard makes any reference to the mineral and vitamin resources of feeding stuffs.

The Scandinavian standard

The " food unit " system was adopted in Scandinavian countries as the result of a large number of feeding trials initiated by N. J. Fjord in Denmark in the 'eighties of the last century. His aim was to establish relative values for different feeding stuffs so that one could be replaced by another in a given ration without upsetting the production of meat or milk by the animal. Unlike Kellner, who worked with store bullocks, he worked with milch cows and pigs, and, subsequently, large scale trials have been conducted with calves, young cattle, dairy and beef cattle, draught horses, fattening pigs, sheep and poultry.

The outstanding feature and merit of the Scandinavian trials is the fact that they are carried out under practical farm conditions, and refer to the particular function required of the feeding stuff. Two methods are employed, the " group " and " period " systems. Group trials are carried out on large farms, where dairy cattle, for example, are divided into a number of fodder groups with at least six animals in each group, those in the different groups being as uniform as possible in size, age, time of calving, yield and quality of milk. The suitability of such animals for the purpose of the trial is determined by their performance in the preliminary period, when, for about three weeks, all groups are similarly fed. In the second period of four weeks one group continues to receive the same diet, while in each of the other groups, one of the feeding stuffs is replaced by a known weight of another and the yield of milk carefully recorded. Finally, all groups receive the same food during the third period of two weeks, and in this way the feeding value of each of the foods under investigation is determined. The following example gives the results obtained in a group trial with dairy cows, where the timothy hay has been replaced in Groups I, II and IV by other types of hay.(3)

Fodder group	Average yield (Kg)	Decrease from preliminary to experimental period	Yield in proportion to Group III	Kg hay to one food unit
Group I 5 Kg clover-grass hay	12·54	— 0·96	+ 0·31	2·38
,, II 5 Kg green fodder hay	12·79	— 0·62	+ 0·65	2·25
,, III 5 Kg mainly timothy hay	12·18	— 1·27	0·00	2·50
,, IV 5 Kg hay from old ley	12·85	— 1·57	— 0·30	2·63

[3] Hansson, Nils, " *Husdjurens Utfodring* " (The feeding of domestic animals), p. 44

In the Scandinavian system, 1 Kg of barley meal is the standard of reference and comprises "one food unit", the food required to produce 3 Kg of milk of average quality. In the above example it is estimated that 5 Kg of timothy hay comprises 2 food units. This weight of clover-grass hay produced 0·31 Kg more milk, an increase equivalent to 0·31 ÷ 3 or 0·1 food unit. Thus, 5 Kg of clover-grass hay had a feeding value of 2·1 food units, so that one food unit would have been provided by 5 ÷ 2·1 or 2·38 Kg. The relative food values in the last column are calculated in this way.

While fairly large numbers of animals are required for group trials, period trials may be conducted on smaller farms, for only one group of animals is used. The trial comprises three periods, each of at least three weeks duration, the first week in each period being a transition period. In the first and third periods the feeding is the same, and the feeding stuff under investigation is introduced in the second period, when the results obtained are compared with the average for the first and third periods.

The food unit system of comparing the relative values of feeding-stuffs has certain advantages over starch equivalent and net energy values. As previously indicated the comparisons are conducted under strictly practical conditions, and the trials are carried out with all classes of farm animals. The Scandinavian workers also recognise that foods vary in value according to the requirements to be met. In particular they claim that food protein, and to a lesser extent carbohydrates, are far more efficiently utilised for milk production than for fattening and, accordingly, a dual set of values has been drawn up. In addition, they indicate the fluctuations which may be expected in the values when foods are above or below medium quality.

As with starch equivalent and net energy values, the use of these food unit values presupposes a suitable proportion of protein in the diet, and adequate supplies of minerals and vitamins. Although extensively used in Scandinavian countries, many difficulties militate against their use in this country, where there is little uniformity in systems of farming, and great variation in the type and composition of feeding stuffs available in different districts.

CHAPTER 14

RATIONING

GENERAL CONSIDERATIONS

THE object of rationing is to satisfy an animal's nutritional requirements for the particular purpose in view, and at the same time to utilise the available food to the best advantage. It is customary and convenient to regard the food consumed by an animal as serving two purposes, namely, maintenance and production. The portion of the ration required for maintenance supplies energy and protein for respiration, circulation of the blood, digestion and other metabolic processes, for the maintenance of body temperature, and the repair of worn-out tissues, without causing an increase or decrease in the live-weight of the animal. Food supplied in excess of these maintenance requirements comprises the production ration, and is used for the growth of the foetus and the young animal, for the production of fat, milk and eggs, and for work in the case of horses.

As indicated in Chapter 12, the system of rationing generally employed in this and other European countries is based on Kellner's work. Energy requirements are expressed as starch equivalents, and it may be well at this stage to remind the reader that fats, carbohydrates and protein all contribute their quota, and that fats and carbohydrates are to a large extent interchangeable, whereas protein is indispensable and irreplaceable in the part it plays in animal nutrition. It is possible to supply an animal with the necessary starch equivalent with foods containing little, if any, protein, and if this were done in practice the animal would starve.

With reference to the protein and non-protein constituents of feeding stuffs, it is necessary to describe briefly two further terms in common use, namely, " protein equivalent " and " albuminoid " or " nutritive ratio." The digestible crude protein (digestible $N \times 6{\cdot}25$), includes digestible pure or true protein and amides. The latter are assumed to possess half the nutritive value of true protein, and this is taken account of in the term protein equivalent, which is half the sum of the digestible crude and digestible true protein. Some feeding stuffs have a high starch equivalent but a low protein equivalent, while others are excellent sources of protein. The albuminoid or nutritive ratio, i.e., the ratio of the digestible non-protein constituents to the digestible crude protein, enables one to see at a glance how a food is balanced in this respect, and affords a means of comparing one food with another. (The digestible fat or oil is multiplied by 2·3, as 1lb produces as much heat in the animal body as 2·3lb of carbohydrate.)

$$\text{Nutritive ratio} = \frac{\text{Per cent digestible (soluble carbohydrates+fibre)+digestible fat} \times 2{\cdot}3}{\text{Per cent digestible crude protein}}$$

Maize and decorticated groundnut cake contain the following percentages of digestible nutrients—

	Crude Protein	*Soluble carbohydrates*	*Fibre*	*Oil*
Maize	7·9	63·7	0·8	2·7
Dec. groundnut cake	42·0	19·7	0·5	6·8

Their nutritive ratios are—

Maize $$\frac{63{\cdot}7+0{\cdot}8+(2{\cdot}7\times2{\cdot}3)}{7{\cdot}9}=\frac{70{\cdot}7}{7{\cdot}9}=9 \text{ (approx.)}$$

Decorticated groundnut cake $$\frac{19{\cdot}7+0{\cdot}5+(6{\cdot}8\times2{\cdot}3)}{42{\cdot}0}=\frac{35{\cdot}8}{42{\cdot}0}=1 \text{ (approx.)}$$

A value of 8 or more is regarded as a wide ratio, and indicates that a food is predominantly rich in carbohydrates and fat, whereas one of 4 or less is a narrow ratio characteristic of foods rich in digestible protein. The above foods are examples of extreme types, while many have a medium ratio of 5 or 6 approximately, and are better balanced foods. Similarly, a ration may be well or poorly balanced for a particular purpose, but no one ration is balanced for all purposes. Young rapidly growing animals need foods rich in protein, and their ration should have a fairly narrow nutritive ratio of about 4, while one with a wide ratio of about 10 suffices to meet the low protein requirements of mature animals, unless they are producing milk or eggs. Nowadays the ratio between the total protein equivalent and total starch equivalent is often used instead of the nutritive ratio (see p. 128).

From what has been said regarding an animal's maintenance and production requirements, it might appear that any mixture of foods adequate from this point of view will constitute a satisfactory ration. This is far from being the case, however, for in addition to starch and protein equivalents, several other factors must be taken into consideration, such as the presence in the foods of adequate supplies of minerals and vitamins. Generally speaking, farm animals receiving a varied diet consisting of a fair proportion of home grown food, particularly green foods grown on fertile soils, will not suffer from any lack of these. Conditions under which deficiencies might arise will be considered when dealing with rations for particular purposes.

Another important consideration is the total bulk of the ration fed. This is limited by the capacity of the alimentary canal and is difficult to measure, for some foods, e.g., coconut cake and meal, bran and dried sugar beet pulp, swell when moistened, and the latter has been known to choke horses by swelling rapidly in the gullet. Such foods are often soaked to avoid distention of the gullet and stomach of stock consuming them. The dry matter of a ration affords a convenient if imperfect guide, and in the case of cattle it is useful to remember that about 3lb of dry food provides suitable bulk per hundredweight ; in general, the aim is to keep the dry matter of rations for cattle, horses and sheep within $2\frac{1}{2}$–3 per cent of their live-weight. A smaller bulk may neither afford the necessary stimulus to peristalsis, nor satisfy the appetite, whereas larger quantities overburden the digestive system. The ability of a food to fill the intestines and promote peristalsis does not depend entirely either upon its dry matter or fibre content, but also upon its capacity to absorb and prevent the passage of water through the intestinal walls. Because of its physical nature bran absorbs water very readily and increases in bulk, while linseed imbibes water in virtue of its high content of mucilages, which constitute its chief carbohydrates. This property of certain foods is closely associated with a further important characteristic of feeding stuffs, namely, their binding or laxative effect.

In general, a high fibre content tends to make foods binding, whereas richness in oil, amides or water, has the reverse effect. Thus hay, straw and fibrous oil cakes, especially undecorticated cotton cake, are usually binding. On the other hand, succulent foods are laxative, as seen when cattle are turned out to grass in the spring ; this is due to the high moisture content of the herbage, and the presence of a large proportion of nitrogenous constituents in the form of amides. For the same reason mangolds are not fed until after Christmas, for in the immature state they cause scouring, being rich in amides, including nitrates, which are converted into asparagine during storage. The presence in foods of moulds, soil, or substances giving rise to poisonous compounds, may have similar effects. In a pronounced form, binding and laxative effects are undesirable, for in the former elimination of waste products is incomplete, and in the latter the food is eliminated before either digestion or absorption have had full play. For preference a ration should be mildly laxative, as the accumulation of waste products is harmful to the animal's health. The herbage consumed by grazing animals during spring and summer ensures the normal functioning of the bowels, and kale, silage and roots fed during the winter attain the same object. Whenever stock tend to scour or become costive, it is advisable to provide food having the opposite effect. Bran mash and succulent foods are used to relieve costiveness, while weatings counteract

scouring in calves, and maize meal or undecorticated cotton cake are given to cattle grazing young succulent herbage for the same purpose.

The palatability of foods is an important property which it is difficult either to measure or explain. Succulent foods and those rich in sugars, oil or protein are usually palatable, for example, young pasture herbage, well-made silage, roots, green crops, sugar beet products, molasses and most oil cakes. On the other hand, very dry and fibrous foods, also those in a very mealy condition, may be less palatable. Even green foods may be so if they have special characteristics which render them bitter or otherwise unpleasant. This has already been suggested as a possible function of mustard-oil glucosides (p. 14), and it is well known that leaves covered with fine hairs, such as those of Yorkshire Fog, or in a coarse condition due to inadequate grazing, tend to be rejected by animals. Coarse tufted herbage should be mown and subsequently closely grazed, and it is rather remarkable that stock will often consume such herbage after it has been mown. It is of the first importance that all food provided should be wholesome and appetising. New foods may be rejected at first, and should be introduced gradually into the ration mixed with foods to which the animals have become accustomed. Mixing with salt, molasses or commercial condiments often improves the palatability of such foods, and a mixture of concentrated foods is generally more readily eaten than a single food. Thus, bean meal is more palatable and digestible when mixed with a lighter food such as bran, crushed oats or flaked maize. Most meals are more appetising when moistened with water, which also renders them less liable to be blown about by the wind or the animal's breath, or to cause respiratory troubles. The once popular practice of mixing chaffed straw with pulped roots was of doubtful value, however, for when one realises that the chief result was to overburden the animal—perhaps a potentially high milk yielder—with indigestible fibre of low feeding value, there is little doubt that the modern practice of allowing the consumption of a more reasonable quantity of unchaffed roughage is the more commendable procedure.

A further important consideration is the effect which some foods have on the fat produced either in the animal body or in the milk. The fat stored by an animal consists of a mixture of glycerides, whose composition is fairly constant and characteristic of the species, but when certain foods are fed in large quantities, there is a tendency for the body fat, and also the milk fat, to assume the consistency of that present in the food. Linseed and its products contain oil rich in unsaturated oleic, linoleic and linolenic acids, and the feeding of linseed cake or other cakes rich in unsaturated oils produces soft fat, while in general carbohydrate foods tend to produce hard fat. Butter of softer consistency is produced when cows go out to

grass in the spring, and a similar effect is produced by linseed cake, soya-beans, groundnuts and several maize products, while pea and bean meals, cotton-seed cake and meal, and coconut cake produce harder butter. In the case of fattening animals, the pig needs more attention than other farm animals, for pigs naturally tend to produce soft fat. Firm bacon fat is produced by barley meal, wheat, peas and beans, while rice bran and meal, maize, oats, soya-bean and groundnut meals have the reverse effect and must be fed in moderation. Soft bacon fat is unpopular because it shrinks excessively when cooked.

Certain foods may also transfer their characteristic flavours or taints to the fat, and it is inadvisable to feed fish meal containing a high oil content to pigs and poultry, because the fishy taint is transferred to pork or bacon fat, and to eggs. White fish meal of low oil content is more suitable, and appears to have no deleterious effect when fed in moderation, but it is usual to exclude it from the rations of pigs during the last stages of fattening.

Milk acquires taints in two ways. Those obtained from foods generally get into the milk via the blood and may be called internal taints, for example the flavour caused by garlic, due to the production of allyl sulphide. Many weeds present in pasture herbage and hay contain volatile fatty acids and essential oils, and are suspected of causing taints, namely, wild onion, chamomile, ox-eye daisy, buttercups, tansy, yarrow, butterwort, mayweed, mint, fool's parsley, water parsnip, wormwood and others. Lucerne hay may produce a taint, and when cows are turned out in the spring, young grass itself frequently causes a grassy flavour. Kale, cabbage, rape, turnips and swedes impart characteristic odours and flavours to milk, and sugar beet tops may cause a fishy taint due to the presence of betaine (p. 26). Flavours imparted to milk by substances present in foods appear to be at their maximum in 1–2 hours after feeding, and as these substances are destroyed or eliminated from the blood, their concentration in the milk also decreases, probably due to diffusion back into the blood. Where possible, crops likely to taint milk should be fed after milking or several hours before, so that any substance causing the taint may leave the system before the next milking. Atmospheric odours or external taints are readily absorbed by milk, and silage, swedes, turnips, cabbage or any foods with pronounced odours, should be fed out of doors or after milking, and uneaten residues removed from the byres.

From what has been said above, it will be obvious that a good stockman must be constantly vigilant in order to apprehend and control any particular effects which a food may have, and which, if neglected, may impair the efforts made to ensure that a ration is otherwise adequate for a given purpose.

CHAPTER 15

THE USE OF STARCH AND PROTEIN EQUIVALENTS IN RATIONING

At the beginning of the previous chapter, attention was drawn to the fact that it is usual to consider the maintenance and production requirements of an animal separately. Although it is convenient to do so in working out a ration, it is not the correct point of view to be taken of the ration as a whole. If, for example, the ration of a dairy cow is composed of hay, straw, roots and concentrated foods, it cannot be assumed that the hay, straw and roots are used for maintenance only and the concentrates for production. All one can say is that the constituents of the ration taken as a whole serve to maintain the animal's bodily functions and to produce a given quantity of milk. A note of warning should be sounded before proceeding to discuss the fulfilment of these requirements, for it should be realised that the standards adopted are far from being absolute, as a good deal of divergence exists between the results obtained by various workers. For instance, it is now generally agreed that 6lb of starch equivalent is required to maintain an ox weighing 1,000lb, but results obtained by various investigators have varied from 4·7 to 7·0lb. Consequently, the standards advocated must be looked upon as a guide to successful rationing rather than figures which must be rigidly adhered to.

Again, the requirements of cattle have received more attention than those of other animals, and are known with a greater degree of accuracy. This is partly due to the fact that most of Kellner's experiments were carried out with oxen, and there is a far greater accumulation of experience in the feeding of cattle indoors with a view to fattening and milk production than is the case with most other animals. Horses have been kept mainly for working, and sheep are fed out of doors. Nevertheless, the success which has attended the scientific rationing of animals has been very considerable, and suffices to justify continuation and extension of the practice.

The nutritive requirements of cattle

1. *Starch equivalent for maintenance* supplies the energy required for essential metabolic processes (p. 120), and unnecessary expenditure of energy in search of food will obviously increase the amount required. This will also vary with the type of animal, but for any one type it varies in direct proportion to the surface area, not the live-weight. Bergmann (1852)

and Muntz (1878) had suggested that a relationship existed between the surface area of the body and the evolution of heat, but Rubner was the first to investigate the problem quantitatively by determining the basal metabolism of adult dogs of different weight, i.e., the minimum energy necessary to maintain the normal temperature and vital functions at rest and without food. The above relationship is usually referred to as Rubner's surface law. It should be noted that maintenance requirements include, in addition, energy expended in moving about.

Since the size of animals is compared by weight and not surface area, it is necessary to see how these are related to one another. The surface area of an animal is proportional to the square of the cube root of its volume, and volume is equal to the weight divided by the density. There is comparatively little difference in the density of different animals, so that their volume is proportional to their weight and their surface is, therefore, approximately proportional to the square of the cube root of the weight. Seeing that energy for maintenance is in direct proportion to the surface area, it was assumed to be proportional to the square of the cube root of the weight.

Recent American investigations have suggested that it is more accurate to regard the maintenance requirements of an animal as varying in proportion to the live-weight to the power of $\frac{3}{4}$ rather than to the power of $\frac{2}{3}$. As a result of practical determinations it is generally agreed that 6 lb of starch equivalent (S.E.) per day suffices to maintain an ox of 1,000 lb live-weight, and Table 9 lists the requirements of cattle of different weights given by Watson and More and based on the American suggestions.([1])

TABLE 9

Live-weight (lb)	Maintenance energy requirement (lb S.E.)	Live-weight (lb)	Maintenance energy requirement (lb S.E.)
100	1·07	900	5·54
200	1·79	1000	6·00
300	2·43	1100	6·44
400	3·01	1200	6·87
500	3·57	1300	7·30
600	4·08	1400	7·72
700	4·58	1500	8·13
800	5·07	1600	8·53

[1] WATSON, J. A. S., and MORE, J. A., 1945, " Agriculture. The science and practice of British farming" p. 496, (Oliver and Boyd)

2. *Protein for maintenance.*—Because of the wear and tear of tissues, animals require a certain amount of protein in order to perform their bodily functions and remain healthy without putting on flesh or producing milk. The amount needed can be measured with a fair degree of accuracy by determining the nitrogen in the urine of a fasting animal and converting this into protein by multiplying by 6·25. Until the results of the above-mentioned American survey were published, it was always assumed that maintenance protein requirements varied in direct proportion to the live-weight, but it now appears preferable to assume proportionality with live-weight to the power of $\frac{3}{4}$ as in the case of S.E. Adopting this innovation the daily protein equivalent (P.E.) required by cattle of different weights is given in Table 10 (the figures also apply to horses and pigs).[2]

TABLE 10

Live weight (lb)	Protein equivalent (lb)	Live weight (lb)	Protein equivalent (lb)
60	0·07	500	0·36
80	0·09	600	0·41
100	0·11	700	0·46
120	0·12	800	0·51
140	0·14	900	0·55
160	0·15	1000	0·60
200	0·18	1200	0·69
300	0·24	1400	0·77
400	0·30	1600	0·85
		1800	0·92

It will be noted that the S.E. and P.E. required for maintenance are in the ratio of 10 to 1.

3. *Starch equivalent for production.*—Animals doing work, or producing fat in the form of body tissue or milk, need additional supplies of energy-giving food. While no accurate estimate of the energy or S.E. needed for work is available, that required for fat production is known fairly accurately, for Kellner found that 4 pounds of starch were necessary to produce 1 lb of fat in the animal body. The position is not as simple as this, for the live-weight increase may be partly due to flesh, involving protein formation as well as fat. This is particularly true in the case of immature animals which need energy for growth and fattening, whereas mature animals put on fat without making appreciable growth, that is, extension of the skeleton and its covering of muscle and flesh. It is also

[2]WATSON, J. A. S., and MORE, J. A., 1945, " Agriculture. The science and practice of British farming," p. 499 (Oliver and Boyd)

true that in the early stages, when water constitutes a considerable amount of the gain in live-weight, less S.E. is required than in the later stages, for the proportion of fat to water increases progressively as the animal gets older. With advancing age there is, therefore, an increase in the S.E. needed per pound of live-weight gained, and the S.E. requirements for fattening are (3)—

TABLE 11

Age and condition of bullock		lb S.E. in excess of maintenance to produce 1 lb live-weight increase
About 2 years ($7\frac{1}{2}$–$8\frac{1}{2}$ cwt live-weight)	Stores	$2\frac{1}{4}$
	Fresh condition	$2\frac{1}{2}$
Over 2 years (9–10 cwt live-weight)	Stores	$2\frac{1}{2}$
	Fresh condition	$2\frac{3}{4}$
	Half fat	3
	Fat	4

The amounts of S.E. and protein required for milk production are considered together in the next section.

4. *Protein for production.*—These requirements are less accurately known than 1–3, and the standards used represent approximate estimates. From the theoretical point of view, no protein should be necessary for producing fat or work, but in practice, it is found that unless a certain amount is provided, the animal is unable to digest the non-protein constituents adequately. It appears that the ratio of digestible protein : non-protein should not be lower than 1 : 10, and for growing and fattening cattle the " balance " of the ration as a whole is expressed as the ratio between the total P.E. and total S.E., that is, for maintenance and production. It should be noted that this is not the " albuminoid or nutritive ratio " referred to on p. 121. The requirements may now be stated as follows(4)—

TABLE 12

	Ratio P.E. : S.E.
Fattening ruminants with no considerable growth	1 : 8
Growing—or growing and fattening ruminants—	
Cattle aged 3 months	1 : 5
,, ,, 6 ,, ...	1 : 6
,, ,, 12 ,, ...	1 : 7
,, ,, 24 ,, ...	1 : 8

[3] Woodman, H. E., 1948, " Rations for Livestock," p. 40, Bulletin No. 48 of the Ministry of Agriculture and Fisheries (H.M. Sta. Office)
[4] Watson, J. A. S. and More, J. A., 1945, " Agriculture. The science and practice of British farming," p. 502 (Oliver and Boyd)

The significance of this method of computing protein requirements for growth and fattening will be more fully understood when considering actual rations in the next chapter.

Both the S.E. and P.E. required for milk production vary with the quality of the milk as indicated in the following table[5]—

TABLE 13

Energy and protein required to produce 1 gallon (10 lb) of milk

Per cent fat	3·50	3·75	4·00	4·25	4·50	4·75	5·25
lb S.E. ...	2·40	2·50	2·60	2·70	2·80	2·90	3·10
lb P.E. ...	0·52	0·55	0·58	0·61	0·63	0·66	0·72

These recommendations are sometimes simplified by stating that Channel Island breeds (i.e., Jerseys and Guernseys) require 3·0lb S.E. and 0·7lb P.E. per gallon of milk, while other breeds require 2·5lb S.E. and 0·6lb P.E.

There is some evidence that for the production of a gallon of milk of average quality (containing 3·75 per cent fat) 0·50lb P.E. is sufficient, so that the figures 0·55 and 0·60 formerly advocated probably ensure the provision of a generous supply of protein. From the practical point of view, reduction of the protein standard is of some importance, since this constituent is more expensive to purchase and more difficult to provide in home grown foods than carbohydrate and oil.

It is now possible to compute rations for various purposes keeping in mind the following attributes of the feeding stuffs at one's disposal—

1. Energy value expressed as S.E. for maintenance and production.
2. Protein equivalent for maintenance and production.
3. Mineral and vitamin content.
4. Special characteristics such as palatability, effect on product, binding or laxative action.
5. Contribution to the " bulk " of a ration.

The main object of the following chapters is to show how rations are built up, and how they may be varied to meet changing circumstances, rather than to give specific rations for definite purposes.

[5]Watson, J. A. S. and More, J, A., 1945., "Agriculture. The science and practice of British farming," p. 558 (Oliver and Boyd)

CHAPTER 16

THE FEEDING OF GROWING AND FATTENING CATTLE

BEFORE describing the feeding of beef cattle, brief reference will be made to the production of veal. For this purpose calves are fed mainly on milk in order to produce meat of a pale colour, and are slaughtered at the age of 1–3 months when they weigh $1\frac{1}{2}$–2 cwt. Surplus calves of the dairy or dual purpose type are chosen and the process of fattening is rapid, for the calves ultimately receive 2–3 gallons of milk daily, and increase in weight at an average rate of about 2 lb per day. The results obtained by feeding substitutes for whole milk, e.g., separated milk supplemented by linseed, oats or flaked maize, are less satisfactory, and veal of lower quality is obtained. Most veal is produced by feeding spring calves in the above manner during late spring and early summer.

Baby beef

Beef cattle are fattened to produce either " baby beef " or " prime beef." In the former case calves of beef breeds or crosses of beef breeds, and also certain dual purpose types are chosen, and for the first three months receive milk and concentrates together with a little hay. Alternatively, the suckling calves are allowed to graze good quality grass or receive cut green food. Feeding must be adequate to ensure good growth without interruption so that the " calf flesh " is not lost, and the foods are increased gradually until at the age of 6 months the animal receives up to 6 lb of hay, 15 lb of roots and 4 lb of concentrates. To encourage rapid growth the cattle may be kept indoors to avoid dissipation of energy, and increasing amounts of suitable foods are fed. At the age of 12 months the cattle should weigh 6–7 cwt, and are slaughtered at 15–18 months weighing 8–9 cwt or more. For the present purpose it is assumed that a live-weight of about 7 cwt has been attained and that it increases at the rate of 2 lb daily. As indicated in the previous chapter, the increase in weight of immature animals consists of protein as well as fat, and it must be admitted that a good deal of uncertainty exists regarding the starch and protein equivalent required for production purposes. The following assessments must be regarded, therefore, as very approximate estimates of the nutrient requirements.

Starch equivalent (S.E.)

Table 9, p. 126, shows that the energy necessary to maintain an animal weighing 800 lb is provided by a S.E. of 5·07 lb, and such an animal in fresh

condition will probably require 2·25 lb S.E. for each live-weight increase of 1 lb; consequently, the S.E. for production is $2{\cdot}25\times2=4{\cdot}5$ lb. The total energy requirements are $5{\cdot}07+4{\cdot}50=9{\cdot}57$ lb S.E.

Protein equivalent (P.E.)

Protein requirements for maintenance are given in Table 10, p. 127 An 800 lb animal requires 0·51 lb P.E. for maintenance. However, as was pointed out in considering the protein requirements for production in the case of fattening animals, it is convenient to consider the balance of the ration as a whole, i.e., the ratio of the total P.E. to the total S.E. (for maintenance and production) given in Table 12. For growing and fattening cattle aged 12 months, as in the present instance, the ratio should be 1 : 7 and, instead of using the figure 0·51, one may ensure that the total P.E. provided is not less than 1/7th of the total S.E., in this case 1/7th of $9{\cdot}57=1{\cdot}37$ lb.

Having calculated the above requirements, it is now necessary to select suitable feeding stuffs, keeping in mind the capacity of the animal and aiming at a total dry matter (D.M.) approximating to $2\frac{1}{2}$ per cent of the live-weight, i.e., about $800\times2{\cdot}5/100=20$ lb. For the present purpose it is assumed that the following foods are available—

	S.E.	P.E.	D.M. (per cent)
(1) Good meadow hay ...	37·0	4·6	85·7
(2) Swedes	7·3	0·7	11·5
(3) Flaked maize	84·0	9·2	89·0
(4) Crushed oats	59·5	7·6	86·7
(5) Linseed cake	74·0	25·1	88·8

The amounts of S.E. and P.E. provided when these are fed in the quantities indicated below are calculated as follows—

(1) 7 lb of good meadow hay will provide	$7\times37{\cdot}0\div100$	=	2·59 lb S.E.
(2) 30 lb of swedes " "	$30\times7{\cdot}3\div100$	=	2·19 lb "
(3) 1 lb of flaked maize " "	$1\times84{\cdot}0\div100$	=	0·84 lb "
(4) 1 lb of crushed oats " "	$1\times59{\cdot}5\div100$	=	0·60 lb "
(5) 1 lb of linseed cake " "	$1\times74{\cdot}0\div100$	=	0·74 lb "
	Total		6·96 lb S.E.

Similarly the protein equivalent and dry matter provided are—

(1)	$7\times4{\cdot}6\div100=0{\cdot}32$ lb P.E.	$7\times85{\cdot}7\div100=6{\cdot}00$ lb D.M.
(2)	$30\times0{\cdot}7\div100=0{\cdot}21$ lb "	$30\times11{\cdot}5\div100=3{\cdot}45$ lb "
(3)	$1\times9{\cdot}2\div100=0{\cdot}09$ lb "	$1\times89{\cdot}0\div100=0{\cdot}89$ lb "
(4)	$1\times7{\cdot}6\div100=0{\cdot}08$ lb "	$1\times86{\cdot}7\div100=0{\cdot}87$ lb "
(5)	$1\times25{\cdot}1\div100=0{\cdot}25$ lb "	$1\times88{\cdot}8\div100=0{\cdot}89$ lb "
	Total=0·95 lb P.E.	Total=12·10 lb D.M.

Since the animal requires 9·57 lb total S.E. and 1·37 lb P.E. this ration is very inadequate; furthermore, seeing that a total of about 20 lb dry matter is permissible, whereas only 12 lb is provided, one can now proceed to increase the quantities of the various feeding stuffs, and again calculate the total S.E., P.E. and dry matter supplied. It may not be possible to achieve the desirable blend of foods even at the second attempt, and considerable adjustments may be necessary in order to compound a suitable ration. Indeed, the above ration was made grossly inadequate in order to emphasise this point; generally it is possible to make an initial estimate which more adequately meets the animal's needs. An animal of this age can consume up to 10 lb of good meadow hay daily and about 40 lb of swedes, so that the amounts of the cheaper feeding stuffs, which contribute mainly to the maintenance part of the ration, may be increased. The quantities of concentrated foods are then adjusted. A ration is now obtained which satisfies the requirements for energy, protein and bulk measured in terms of dry matter—

(1) 7 lb hay	will provide	2·59 lb S.E.,	0·32 lb P.E.	and	6·0 lb D.M.
(2) 40 lb swedes	,, ,,	2·92 lb ,,	0·28 lb ,,		4·6 lb ,,
(3) 2 lb flaked maize	,, ,,	1·68 lb ,,	0·18 lb ,,		1·8 lb ,,
(4) 3 lb crushed oats	,, ,,	1·79 lb ,,	0·23 lb ,,		2·6 lb ,,
(5) $1\frac{1}{2}$ lb linseed cake	,, ,,	1·11 lb ,,	0·38 lb ,,		1·3 lb ,,
The ration provides		10·09 lb S.E.	1·39 lb P.E.	and	16·3 lb D.M.

In order to meet the requirements at a still later stage, when $2\frac{1}{2}$ to 3 lb of S.E. may be necessary for 1 lb of live-weight increase, additional concentrates are added to make a total of about 8 lb, and these should be carbohydrate-rich foods such as 3 and 4 above. The animal may also consume up to about 10 lb of hay and satisfy its appetite for bulky material when the total dry matter will approach 20 lb. It would not be difficult to supply all the protein without using linseed cake, but it is an advantage to include this food, because it makes the animal's skin soft and pliable, and imparts a healthy bloom to the coat.

The ration could be varied considerably as regards the actual feeding stuffs employed. Swedes could be replaced by an equal weight of mangolds, or by a smaller weight of good silage or kale; part of the concentrates might also be replaced by some or all of the following: barley meal, bean meal and undecorticated groundnut cake.

Whereas after the Great War of 1914-18 there was an increasing demand for smaller joints of beef, the popularity of "baby beef" appears to have waned considerably, and the demand for meat during the recent war years has encouraged the production of heavier more mature animals.

The production of prime beef

In contrast to animals designed for baby beef, which make rapid growth and fatten simultaneously, those chosen to produce prime beef pass through a " store " period of 2–2½ years. During this time the animals grow but do not fatten, and are kept on pasture of comparatively poor quality in the summer, and in the winter are fed indoors or run out on pasture with some hand feeding with poorer quality hay or reasonably good straw. Store animals may increase in weight by about 1 lb daily, and an animal weighing 8 cwt will require 5·54 lb S.E. for maintenance and 2 lb S.E. for production, a total of 7·54 lb, the total P.E. being about one-eighth of this or 0·94 lb. An animal grazing poor quality herbage expends a good deal of energy, and for this 1–3 lb S.E. is allowed. The dry matter consumed should approximate to 2½ per cent of the live-weight, i.e. $900/100 \times 5/2 = 22{\cdot}5$ lb, provided in pasture herbage or in a ration of hay, roots and concentrated foods—

	S.E.	P.E.	D.M. (per cent)
Poor meadow hay	22·0	3·0	85·7
Swedes...	7·3	0·7	11·5
Crushed oats	59·5	7·6	86·7
Palm kernel cake	73·2	17·0	89·0

The 5·5 lb S.E. for maintenance may be provided by hay and swedes. Thus 14 lb hay will provide $14 \times 0{\cdot}22 = 3{\cdot}08$ lb S.E., and 30 lb swedes $30 \times 0{\cdot}073 = 2{\cdot}19$ lb S.E., a total of 5.27 lb. This leaves $7{\cdot}54 - 5{\cdot}27 = 2{\cdot}27$ lb S.E. to be provided, and 4 lb oats would provide 2·38 lb. The ration would then be—

	S.E. (lb)	P.E. (lb)	D.M. (lb)
14 lb hay	3·08	0·42	12·0
30 lb swedes	2·19	0·21	3·5
4 lb crushed oats	2·38	0·30	3·5
Total ...	7·65	0·93	19·0

This barely meets the animal's requirements, but the substitution of 1 lb of crushed oats by 1 lb of palm kernel cake suffices, and the ration would now provide 7·8 lb S.E., 1·0 lb P.E. and 19 lb dry matter.

Store animals are often reared in one part of the country and bought for fattening in another. The selection of animals for this purpose is of great importance, for animals differ greatly in their response to different systems of feeding and management and, as stated by Linton, " the successful fattening of store cattle may be described as an art assisted by

science."[1] Many important factors relating to successful rearing and general management of cattle are described in such standard works as those referred to at the end of this book, but the art of the feeder has to be acquired by experience.

It is of prime importance that fattening animals be given rest and quiet, and it has been said that " a good bed is worth a pound of cake ". For fattening purposes bullocks and heifers are reared as stores until on an average they are 2 years old, although fattening may commence a little earlier in the case of early maturing breeds, or 6–12 months later with late maturing animals. Generally, the aim is to secure a live-weight increase of some 2lb daily, so that a store weighing 7–9cwt is sold in prime fat condition weighing 10–11 cwt or more at the end of a fattening period of 4–6 months. Feeding may proceed entirely on pasture, in courts and stalls, or may commence on pasture and finish indoors.

The present aim is to show how the requirements of fattening bullocks can be met by feeding home grown and purchased foods, and to consider pasture herbage from this point of view. The nutritional requirements of a 9cwt store bullock for fattening at the rate of 2lb per day may be estimated by reference to pages 126–8.

Energy and protein for maintenance and production

Two facts must be kept in mind in calculating the starch equivalent required. In the first place, a 9cwt animal will weigh about 11cwt at the end of the fattening period, the corresponding energy requirements for maintenance being 6 and 7lb S.E. respectively. Secondly, as was pointed out in the previous chapter, the S.E. required per lb live-weight gained increases from 2·25lb at the beginning to 2·5, 3 and even 4lb to bring an animal to a state of absolute fatness. This is uneconomical and is often avoided in practice. The amount of starch equivalent increases from $(6+2{\cdot}25\times2)=10{\cdot}5$lb to $(7+3\times2)=13$lb or a little more, and many authorities allow 11 and 13·5lb respectively. Comparatively little protein is necessary, and it suffices to maintain a ratio of 1 part total P.E. to 8 parts total S.E.; in the case under consideration the P.E. amounts to $(11 \text{ to } 13{\cdot}5)\div8$ or 1·4 to 1·7lb.

Feeding on pasture

It should be realised that pasture herbage is subject to very great variation in composition ; in the spring, short succulent herbage may contain as much as 30 per cent of crude protein in its dry matter, and fulfil the function of a highly concentrated food, whereas, if allowed to mature

---

[1]LINTON, R. G., and WILLIAMSON, G., 1943, " Animal nutrition and veterinary dietetics," p. 344 (Green and Son, Ltd., Edinburgh)

and run to head, the figure may fall to one-third of this and the herbage becomes a roughage. It will be evident, therefore, that if pasture is to contribute materially to fattening, grazing must be skilfully managed. The aim should be to obtain growth approximating in composition to that of herbage cut at intervals of not more than four weeks. Even so the composition will vary to some extent with the type of herbage, particularly clover content, and the fertility of the soil. In the following discussion it is assumed that the composition is that usually given to such herbage.

Pasture herbage grazed at intervals of 3 and 4 weeks respectively has on an average the following starch and protein equivalents—

	S.E.	P.E.
Three-weekly intervals	14·6	3·4
Monthly intervals ...	13·4	2·4

A 1,000lb bullock will consume an amount of dry matter approximately equal to $2\frac{1}{2}$ per cent of its live-weight, probably about 22lb daily. The above herbage contains on an average 20 per cent of dry matter, so that the animal is capable of consuming about 110lb. This will contain 1·1 times the above figures of S.E. and P.E., i.e., for herbage grazed at intervals of 3 weeks, 16·1lb S.E. and 3·7lb P.E., and for that grazed at monthly intervals, 14·7lb S.E. and 2·6lb P.E. It provides more energy and protein than is required to fatten a two-year old, 9 cwt bullock, even when—as is usual—an additional 1lb of S.E. is allowed to make good that expended in searching for food. While first class pastures will probably attain this high nutritive standard, the herbage of second class and poorer grazings will fall short of this in energy value, but may contain sufficient protein to meet the above requirements. It is customary to supplement such herbage with carbohydrate-rich foods such as maize meal or crushed oats. In general, good pasture herbage provides protein in excess of the animals' requirements, whereas the supply is controlled under indoor feeding conditions. Rich herbage may induce scouring for which a careful watch must be kept, and the former practice of feeding concentrates such as undecorticated cotton cake to cattle fattening on pasture had the advantage of overcoming this tendency.

Winter feeding

Winter feeding is carried out indoors either in stalls or in covered or partly covered yards in sheltered positions. The maintenance requirements are supplied by home grown roughages, hay and straw, and by roots. Good silage, kale, home grown and purchased concentrates supply energy and protein for production.

As indicated above a 9 cwt bullock requires 10·5–11·0lb S.E. and 1·3–1·4lb P.E. for fattening at the rate of 2lb daily. For the purpose of

illustration it is assumed that the following foods are available in ample amounts—

	S.E.	P.E.	D.M. (per cent.)
Good meadow hay	37·0	4·6	85·7
Oat straw	20·0	0·9	86·0
Mangolds	6·2	0·4	12·0
Crushed oats	59·5	7·6	86·7
Bean meal	65·8	19·7	85·7
Decorticated cotton cake ...	68·4	34·6	90·2

All are home-produced with the exception of the cotton cake.

	S.E. (lb)	P.E. (lb)	D.M. (lb)
12 lb meadow hay will supply ...	4·44	0·55	10·3
4 lb oat straw ,, ,, ...	0·80	0·04	3·4
40 lb mangolds ,, ,, ...	2·48	0·16	4·8
4 lb crushed oats ,, ,, ...	2·38	0·30	3·5
1 lb bean meal ,, ,, ...	0·66	0·20	0·9
1 lb decorticated cotton cake ...	0·68	0·35	0·9
	11·44	1·60	23·8

The above ration provides ample energy and protein, contained in a suitable bulk, for the earlier part of the fattening period, and almost enough protein for the later stages, during which only the carbohydrate-rich constituents need to be increased, and at the same time the roughages may be decreased. It is usual, however, to use linseed cake during the last month as it improves the appearance of animals. During the fattening period the ration is increased gradually until eventually the animal is receiving the following amounts of foods—

	S.E. (lb)	P.E. (lb)	D.M. (lb)
14 lb good meadow hay ...	5·18	0·64	12·0
40 lb mangolds	2·48	0·16	4·8
6 lb crushed oats	3·57	0·46	5·2
3 lb linseed cake	2·22	0·74	2·7
	13·45	2·00	24·7

It is possible, of course, to vary the individual feeding stuffs considerably. Instead of meadow hay, seeds hay and straw might be used, mangolds could be replaced by swedes, kale or silage, and the concentrated foods by maize meal, flaked maize, barley meal, bran, dried sugar beet pulp, palm kernel cake or groundnut cake.

In practice the supply of hay is controlled, but animals are allowed as much straw as they will eat and, as chaffing appears to have little practical advantage, especially when the labour involved is taken into account, straw should be fed long. Roots too may be fed whole, and it is unnecessary to pulp them, although slicing facilitates mastication by stock under 2 years old which are losing their milk teeth. It is common practice to feed the animals twice or thrice daily, and this avoids disturbing them unduly and allows ample rest. Half the roots and concentrates are given in the morning and half in the evening, and hay and straw supplied in the racks, although some farmers chaff and mix the straw with the roots and concentrates.

It has been estimated that fattening cattle require about 1 gallon of water per cwt live-weight, and it should be available in automatic drinking bowls or offered twice daily. Animals receiving very large amounts of roots, e.g., a cwt or more daily, may not drink any water, but it should always be offered to them. Once a system of feeding has been adopted, it should be strictly adhered to, and every effort made to secure comfortable conditions including adequate ventilation and bedding. For this reason ample manger space is essential, and aggressive animals must be removed when animals are housed in yards or courts ; dehorning is sometimes resorted to for similar reasons.

Occasional washing and grooming, including dusting with lice-killing powders such as D.D.T., are well worth while, and the art of the successful feeder consists in careful attention to such details as these, whereby animals are maintained in a well-fed contented condition conducive to fattening.

THE FEEDING OF DAIRY COWS

MILK is produced from blood by a series of complicated physico-chemical changes which take place in the mammary glands and, at the outset, it may be well to outline briefly the chemical composition of cow's blood and milk. The data given in the following table are average figures, and both fluids are subject to considerable variation in composition.

TABLE 14

Average composition	*Cow's Blood* [1]	*Cow's Milk* [2]
Water	80·89	87·54
Total solids	19·11	12·46
Haemoglobin	10·31	—
Casein	—	2·63
Albumin	6·98	0·31
Globulin	—	0·11
Lactose	—	4·70
Sugar (glucose)	0·07	—
Fat	0·057	3·71
Ash	(not given)	0·76
Soda Na_2O	0·364	0·068
Potash K_2O	0·041	0·190
Lime CaO	0·007	0·176
Phosphoric acid P_2O_5 ...	0·040	0·233
Chlorine Cl	0·308	0.106
Iron Fe	0·019	1-2 parts per million

Several important facts emerge from these figures. Certain substances present in blood are absent in milk and vice versa, e.g. glucose and haemoglobin are present in blood but not in milk, while casein and lactose are present in milk only. The difference in the percentage of certain constituents common to both fluids is also of interest, notably albumin, fat and minerals. Compared with milk, blood is relatively rich in total solids, soda, chlorine and iron, whereas milk is much richer than blood in potash, lime and phosphoric acid. Although blood and milk differ so

[1] DUKES, H. H., 1947, " The physiology of domestic animals," pp. 51–54 (Comstock Publishing Company Inc. Ithaca, N. York) The iron content of cow's blood is expressed by Dukes as Fe_2O_3 Here it is expressed as Fe, the conversion being made to facilitate comparison with cow's milk.

[2] LING, E. R., 1944, " A textbook of dairy chemistry," pp. 44 and 73 (Chapman and Hall)

widely in composition, the two fluids are isotonic, so that the changes which take place in the mammary glands are brought about without disturbing the balance of the substances in true solution responsible for osmotic pressure.

Milk contains all substances necessary for nutrition, but tends to be deficient in iron, copper, vitamins C, D and sometimes A—depending on season and food—which, combined with the fact that it does not provide sufficient bulk for more mature animals, militates against its being a perfect food except for the very young calf. Nevertheless, it is evident that milk production makes heavy demands upon the animal, which must be met by the food supplied. Despite its importance, however, it must be clearly understood that feeding is far from being the only factor involved : heredity and general management are of fundamental importance, and it is well known that different breeds vary greatly in milking capacity. Friesians generally produce high yields of milk of moderate quality, whereas Jerseys and Guernseys are renowned for the richness rather than the volume of their milk, and it should be noted that allowance is made for this difference in quality in considering food requirements (p. 129). A given animal will produce her largest daily volume of milk from about the 6th to the 10th week after calving, and no amount of feeding will restore the yield when the natural decline sets in. On the other hand, it is not uncommon to find that it is difficult to " dry off " some cows. These facts in no way detract from the advantages which accrue from judicious rationing, which aims at stimulating the flow of milk to a maximum, and also adjusts the food supplied to meet an animal's production requirements as reflected in her milk records. Before proceeding to compute rations for dairy cows, it will be advantageous to give a brief account of their more general requirements.

Requirements of the dry in-calf cow

In a well-managed dairy herd it is customary to prepare the cows for milk production some time before they are due to calve. They are dried off some six to eight weeks prior to calving, and thus ensured of an adequate rest between their periods of lactation. During this dry period, feeding should be so adjusted as to bring them into moderately good condition, so that, at calving, they have a reserve of flesh and fat that will serve to tide them over a difficult period. The ration should be mildly laxative and not bulky. When obtainable, succulent foods are particularly well suited for the purpose, but when these are unavailable moist bran or linseed may be fed with good results.

It is generally agreed that a maintenance ration plus 1 lb of S.E. including 0·3 lb of P.E. are sufficient provision for the growing foetus

during the last few months, and it is usual to allow in addition to the maintenance requirements, a ration of concentrates, which is increased from 2 or 3 pounds some 6 weeks before calving to about three times this amount during the last fortnight or so. Some stockmen provide half the ration of concentrates which they estimate will be required at the period of maximum milk production ; others provide still more liberally for the " steaming up " process as this preparatory feeding is popularly known, and practical experience shows that generous provision at this stage has several advantages. It provides the animal with reserves adequate to carry her over the difficult period immediately after calving when the ration should be very light. Further, it not only prepares her for the increasing demands of lactation, but also favourably affects the volume of milk produced. Finally, if the constituents of the ration are carefully chosen, the animal may accustom itself to the foods to be fed for milk production, and so avoid any check in the flow of milk which might attend the rejection of any particular food. Steaming up also has a beneficial effect on the live-weight, size and vigour of the calf at birth. For several days before and after calving, sufficient laxative foods in the form of succulents or suitable oil cakes and bran serve to ensure healthy action of the bowels.

It is possible, of course, that during the period under discussion the cow is on pasture, and much less attention need be paid to feeding, for, with good quality herbage, no concentrated foods are required, whereas, with inferior grazing, the reverse is true. In short, the feeding of pregnant cattle calls for the unceasing vigilance of the stockman who must vary his treatment according to circumstances.

After calving the cow may go off her food, and little, if any, concentrates are fed for a few days, but are gradually introduced on the fourth or fifth day. It is some time, however, before the amount fed is adequate to meet the demands of milk production, so that, until this is achieved, the cow is underfed and dependent upon the reserves built up during the preparatory period. This is particularly true in view of the fact that the first milk or colostrum secreted after parturition contains nearly twice the amount of total solids present in normal milk, including relatively large quantities of protein (mainly albumin), fat, minerals and vitamins. Colostrum is specially designed to meet the requirements of the young calf, and gradually changes in composition over a period of 3–6 days, and is sold as milk on the 4th day.

This period of restricted feeding partly accounts for the rapid loss in weight of high milk yielders after calving, which may occur until the ration fed meets the animal's requirements. When these have been satisfied, it pays to provide two or three extra pounds of concentrates, and to continue to do so while the yield of milk tends to increase. This helps to

ensure that the animal is producing milk up to its maximum capacity, which is not being restricted for the want of adequate food supplies. The ration may afterwards be adjusted to meet the theoretical requirements.

Feeding on pasture

As in the case of fattening cattle it is assumed, in the first place, that the cow is grazing good quality pasture (see p. 135). Grazed at 3 and 4-weekly intervals this has a S.E. of 14·6 and 13·4 respectively : the corresponding P.E. figures are 3·4 and 2·4. A ten cwt cow will consume about 3lb of dry matter for each cwt of live-weight, i.e. 30lb. Since the herbage under consideration contains on an average 20 per cent of dry matter, 30lb will be present in 150lb of herbage. An animal consuming 150lb of pasture intensively grazed will receive the following amounts of S.E. and P.E.

	S.E. (lb)	P.E. (lb)
Pasture grazed at 3-weekly intervals	21·9	5·1
,, ,, 4- ,, ,, ...	20·1	3·6

Reference to Tables 9 and 10 (pp. 126-7) shows that the maintenance requirements of a 10 cwt cow are 6·5lb S.E. and 0·65lb P.E. In the case of herbage grazed at 3-weekly intervals, this leaves an excess of 21·9 — 6·5 or 15·4lb S.E. and 4·45lb P.E. for milk production ; similarly, that grazed at monthly intervals provides 20·1 — 6·5=13·6 lb S.E., and 3·6 — 0·65= 2·95 lb P.E. For each gallon of milk of average quality (containing 3·7 per cent of fat), 2·5 lb S.E. are required and 0·55 — 0·60 lb P.E. The shorter herbage provides enough S.E. for 15·4÷2·5=6·2 gallons of milk, and sufficient P.E. for 4·45÷0·6=7·4 gallons ; the longer type supplies S.E. for 13·6÷2·5=5·4 gallons, and P.E. for 2·95÷0·6=4·9 gallons. Consequently, one may safely conclude that good quality herbage intensively grazed suffices to maintain a 10-cwt cow and produce 5 gallons of milk (as well as providing for exercise), while protein is provided in excess of maintenance and production requirements. This is found to be the case in the early part of the season, but as the season advances the herbage deteriorates, for the grasses tend to mature despite careful management, and it may be necessary to provide some concentrated food for high milk yielders.

One great advantage accompanying the outdoor feeding of dairy cows is that the fresh green herbage provides abundant minerals and vitamins in addition to energy and protein, and in this connection it is of the first importance to maintain the lime and manurial status of the soil, for each gallon of milk sold off the farm takes away approximately $\frac{1}{3}$ oz of phosphoric

acid (P_2O_5), and $\frac{1}{4}$oz of lime (CaO). Adequate dressings of lime and manures not only improve the mineral content of the grasses, but also encourage the growth of clovers and other legumes particularly rich in lime.

From the foregoing it will appear that the feeding of dairy cows giving up to 5 gallons of milk presents little difficulty when good pasture land is managed skilfully. The position is not quite as simple as this, because herbage varies considerably in composition during the summer, even when closely grazed, and the only criteria of adequate energy and protein supplies are the milk records and the condition of the animals. If it is found necessary to provide concentrated foods, these should be predominantly starchy in nature, unless the yield of milk is very high, when balanced concentrates must also be given. Careful watch must, of course, be kept for scouring on rich pasture.

Winter feeding

There is less uncertainty regarding the composition of the foods available during the winter feeding period, when the main problem is the provision of adequate amounts of high quality succulent foods and concentrates in order to minimise the drop in milk yield at the advent of indoor feeding. During the winter the maintenance requirements of dairy cows are largely satisfied with hay, straw and roots, whereas such home grown foods as silage, kale, beans, linseed and cereals may contribute to the production ration. It is worth emphasising the fact that while it is easy enough to provide the energy requirements from home grown foods, much greater difficulty is experienced in providing the necessary protein. The difficulty of maintaining a high level of milk production with home grown foods arose during the war, and while it is possible to satisfy the needs of animals giving yields of milk up to 3 gallons, it is much more difficult to provide the necessary protein for higher yields without resorting to imported oil cakes. Further reference will be made to this problem when considering rations for high-yielding cows.

As mentioned above, hay, straw and roots provide the basis of the maintenance ration. The amount of hay fed may vary from about 14–20lb, depending on the type of animal and the milk yield. The best meadow and seeds hay are reserved for the heavy yielders, and straw is fed only to those giving low or moderate yields. The quantity of roots fed will depend on the other constituents of the ration and on the yield of milk; about 40lb is a suitable quantity for average yields. A wide range of concentrates is available in normal times, comprising home grown cereals and imported oil cakes, as well as such starchy foods as maize products. Of the home grown foods, none is more variable in composition than

meadow hay (p. 86). When allowed to become overmature before harvesting, and if exposed to rain for prolonged periods, it becomes little better than straw. On the other hand, comparatively immature hay harvested under favourable conditions may make some contribution to the production ration. Similar conditions affect the quality of seeds hay, whose composition also depends to a large extent on the proportion of clover present.

In considering summer feeding it was found that a 10 cwt dairy cow giving milk of average composition requires 6·5lb S.E. and 0·65lb P.E. for maintenance. It will be instructive to consider how these requirements may be satisfied by feeding roots and meadow hay of the following quality—

	S.E.	P.E.	D.M.(per cent
Poor meadow hay	22·0	3·0	85·7
Very good meadow hay	48·0	7·8	84·0
Swedes...	7·3	0·7	11·5
A 14 lb poor meadow hay provide (in lb)	3·08	0·42	12·0
40 lb swedes ,, ,,	2·92	0·28	4·6
	6·00	0·70	16·6
B 14 lb very good meadow hay ,, ,,	6·72	1·09	11·8
40 lb swedes ,, ,,	2·92	0·28	4·6
	9·64	1·37	16·4

It is evident that 40lb of swedes and 14lb of poor meadow hay barely suffice for maintenance, whereas the same quantities of swedes and very good meadow hay provide an excess of 9·64 — 6·5=3·14lb S.E. and 1·37 — 0·65=0·72lb P.E., more than enough for the first gallon of milk. When one considers the bulk of hay harvested in this country, the importance of securing it in good condition is obvious. This example also shows that it is quite simple to provide for the first gallon of milk even where the hay is poor, for a 10 cwt animal can consume more dry matter than is contained in A, so that the amount of hay could be increased and supplemented by suitable concentrates. The object of these examples is to direct attention to the very appreciable difference in nutritive value of poor and very good meadow hay rather than to compute a ration for a cow yielding one gallon of milk, for such an animal requires more than 16½lb of dry matter. In practice, cows yielding 2 gallons or less would receive

a good deal of straw instead of the whole or part of the medium quality meadow hay.

Requirements of a 10-cwt cow yielding 2 gallons milk per day containing 4.25 per cent fat—

S.E. for maintenance 6·5 lb ; for production 2·70×2=5·4 lb. Total=11·9 lb
P.E. for maintenance 0·65 lb ; for production 0·61×2=1·22 lb. Total= 1·87 lb

Foods available

	S.E.	P.E.	D.M. (Per cent)
Meadow hay (medium quality) ...	30·0	3·8	85·7
Oat straw	20·0	0·9	86·0
Thousand-headed kale	10·3	1·4	15·8
Crushed oats	59·5	7·6	86·7
Beans	65·8	19·7	85·7
Decorticated groundnut cake ...	73·0	41·3	89·7

Ration

	S.E. (lb)	P.E. (lb)	D.M. (lb)
14 lb meadow hay (medium quality) will provide	4·20	0·53	12·0
7 lb oat straw ,, ,,	1·40	0·06	6·0
30 lb kale ,, ,,	3·09	0·42	4·7
2 lb crushed oats ,, ,,	1·19	0·15	1·7
2 lb beans ... ,, ,,	1·32	0·39	1·7
1 lb decorticated groundnut cake ,,	0·73	0·41	0·9
Total =	11·93	1·96	27·0

Instead of kale, good silage made from young grass, grass and clover, or oats and vetches could be used, but, as silage usually contains more dry matter than kale (about 25 instead of 16 per cent), a smaller quantity—about 20lb—would suffice, assuming that both feeding stuffs were similar as regards S.E. and P.E. Alternatively, mangolds or swedes could be used, but in this case the ration would require rather more adjustment seeing that roots contain only about 12 per cent of dry matter, and less S.E. and P.E. than kale and good quality silage. The reader would find it instructive to carry out such modifications.

The ration contains a very small proportion of purchased cake, which could be excluded altogether for cows giving 2 gallons of milk, and the protein supplied by home grown foods such as beans, kale and good

silage. The amount of purchased cake increases with the milk yield, because it is then essential to provide the nutrients in a more concentrated form in order to keep the total dry matter within reasonable limits. While yields of milk in the region of 3 gallons are moderate, yields of 5 gallons are quite common, and the requirements of an animal giving this volume of milk will be considered in order to illustrate the way in which the ration becomes more concentrated.

Requirements of an 11-cwt cow giving 5 gallons of milk daily containing 3.75 per cent fat—

S.E. for maintenance=6·9 lb. ; for production 2·5×5=12·5 lb. ;
Total S.E.=19·4 lb

P.E. for maintenance=0·7 lb. ; for production 0·6×5=3·0 lb ;
Total P.E.=3·7 lb

An animal of this live-weight should be able to consume about 30–33 lb of dry matter per day. The previous ration computed for a 10-cwt cow yielding 2 gallons of milk contained 27 lb dry matter, and it is evident that in catering for an additional 3 gallons one must be careful to keep the total bulk within reasonable limits. From previous examples it will be realised that roughages and succulent foods provide the energy and protein for maintenance, and if of good quality, some of the production ration as well. Thus in the ration for the 2-gallon cow, 14 lb hay, 7 lb oat straw and 30 lb kale provided 8·7 lb S.E. and 1 lb P.E., whereas the maintenance requirements were 6·5 lb S.E. and 0·65 lb P.E. The bulk of the production requirement was provided by 5 lb of concentrates, and with higher milk yields the proportion of concentrates fed steadily increases ; actually about 3½ lb suitably balanced, i.e., containing approximately 2·5 lb S.E. and 0·6 lb P.E., suffice for the production of each gallon of milk. It is an advantage to consider the production portion of the ration first, and then to adjust the constituents of the maintenance ration so that the total dry matter falls within the prescribed limits.

In the present instance 3½ lb×5=17½ lb of balanced concentrates will be fed and, in order to estimate the quantity of dry matter supplied, it is worth remembering that concentrated foods contain on an average approximately 86 per cent, so that 17½ lb contain 17·5×86/100 or 15 lb dry matter. This leaves some 15–18 lb to be provided in the maintenance portion of the ration. Only hay of good quality, whether meadow or seeds hay, should be fed to cows giving yields of milk in excess of 2–3 gallons.

Ration for a dairy cow yielding 5 gallons of milk containing 3.75 per cent fat—

	S.E. (lb)	P.E. (lb)	D.M. (lb)
12 lb seeds hay (S.E. 38·4; P.E. 6·4; D.M. 84·8 per cent) provide	4·61	0·77	10·2
20 lb green oat and vetch silage (S.E. 12·8; P.E. 1·6; D.M. 27·3 per cent) provide ...	2·56	0·32	5·5
17½ lb balanced concentrates (containing 2½ lb S.E. and 0·6 lb P.E. per 3½ lb) provide	12·50	3·00	15·0
	19·7	4·1	30·7

As regards the balanced concentrates, a wide choice is available. Some oil cakes, for example, palm kernel and coconut cake, are balanced for milk production, 3½ lb providing approximately 2·5 lb S.E. and 0·6 lb P.E., and it is possible to feed them alone or mixed with other cakes and meals. In compounding mixtures for production, however, it is well to remember that the proteins of certain foods may be deficient in one or more of the essential amino-acids, whereas proteins derived from several sources may supplement one another in this respect. For this reason it is inadvisable to limit the foods used in the production ration to one or two types, and this is particularly true when they are required to feed cows giving high yields of milk.

The mixtures given below are suitable when fed at the rate of 3½ lb per gallon of milk of average composition—

Feeding stuff	*Parts by weight*	*Feeding stuff*	*Parts by weight*
A		B	
Crushed oats	3	Maize meal	2
Bean meal	1	Crushed wheat	1
Coconut cake...	2	Palm kernel cake	2
Decorticated groundnut cake	1	Cotton-seed meal	1
C		D	
Crushed barley	1	Flaked maize	3
Flaked maize	2	Cracked beans	1
Bean meal	2	Coconut cake	2
Linseed cake	2	Decorticated cotton-seed cake	1
E		F	
Crushed oats	1	Crushed oats	2
Crushed wheat	2	Maize meal	1
Maize meal	1	Maize gluten feed	2
Linseed cake	1	Linseed cake	1
Decorticated groundnut cake	1	Decorticated cotton-seed cake	1

Almost any number of mixtures may be drawn up, but the combination chosen will depend upon the foods available and the supply, their relative cost and, to some extent, the nature of the maintenance ration. If, for instance, cattle are being fed on liberal amounts of succulent foods such as kale, roots or silage, with a tendency to produce scouring, it is wise to include cereal products and cotton-seed cake which help to counteract this. (For the same reason hay, straw or cotton-seed cake are sometimes fed to animals grazing young, rich herbage). On the contrary, if the hay or other constituents of the maintenance ration are binding, such laxative foods as linseed, coconut or groundnut cakes may be fed.

While mixtures of this kind may be made up in normal times, imported concentrates are now used mainly to prepare "national compounds" balanced for milk production etc. (p. 101).

Cows yielding more than five gallons

From the preceding discussion it will be evident that for cows giving very high yields of milk, e.g., up to 8 or even 10 gallons or more, the greater part of the ration will consist of concentrated foods. A cow yielding 8 gallons will consume upwards of 28lb, allowing $3\frac{1}{2}$lb per gallon ; this leaves a very small margin for roughages and roots. The essential principles underlying the feeding of such animals are the provision of the necessary nutrients in a still more concentrated form—e.g., by incorporating linseed in the production mixture—so that not more than 3lb need be fed per gallon of milk, or limitation of the roughages to about 6–10lb. Hay must be of the highest quality, and if it fails to meet the maintenance requirements, flaked maize, bran or similar foods are added ; alternatively, the hay may be replaced by first quality dried grass. Little room remains for succulent foods, which are omitted altogether, fed in small amounts only, or replaced by a food such as sugar beet pulp with similar action on the bowels without being so bulky. Since the large amounts of concentrates fed to high yielding cows usually contain a high proportion of laxative oil cakes, there is less need for succulent foods.

Assuming that $3\frac{1}{2}$lb of mixed concentrates are fed per gallon, an 8-gallon cow will consume 28lb containing approximately 20lb of S.E. and 4·8 lb P.E., which are also the production requirements for this quantity of average milk ; this amount of food contains $28 \times 86 \div 100 =$ 24lb dry matter. In addition, an animal weighing 11 cwt requires 6·9lb S.E. and 0·7lb P.E. for maintenance, which must be supplied in not more than some 10lb of dry matter. Very good meadow hay has a S.E. of 48 and a P.E. of 7·8 ; 8lb would supply 3·84lb S.E. and 0·62lb P.E. and it remains to supply about 3·1lb S.E. and a little P.E. Four pounds

of flaked maize (S.E. 84·0 ; P.E. 9·2) provide 3·4lb S.E. and 0·4lb P.E. The hay and maize contain 84 and 89 per cent dry matter respectively, and contribute $[(84\times8\div100)+(89\times4\div100)]$ lb or 10·3lb dry matter in all. The total dry matter is thus kept down to 34·3lb. Instead of maize, equivalent amounts of other cereal concentrates might be used, e.g., crushed oats, wheat or barley. A small quantity of roots in the form of 10lb of mangolds or swedes might also be included in addition to or in place of a pound or so of hay.

One may then compute rations for cows yielding 8 or even 10 gallons of milk, but it should be realised that the satisfying of nutritional requirements is no guarantee that a particular animal will eat the food provided, and each individual giving high yields constitutes a separate problem to be studied very carefully until one is quite satisfied with the response obtained. It may also be noted that such animals may be fed and milked thrice daily.

Mineral and vitamin requirements for milk production

No study of the nutritional requirements of dairy cows is complete without reference to two groups of substances of fundamental importance in milk production, namely, minerals and vitamins. Cattle grazing good pasture are unlikely to suffer deficiency of either, except possibly magnesium and certain trace elements (see Chapter 4), especially when due attention is paid to maintaining the lime and mineral status of the soil. It is during the winter period that deficiency is likely to occur, particularly in the case of high yielding animals. Reference to the figures given on p. 138 shows that milk contains a variety of mineral substances, and it may be shown that each gallon contains approximately $\frac{1}{6}$-oz of chlorine (Cl), $\frac{1}{4}$-oz of lime (CaO) and $\frac{1}{3}$-oz of phosphate (P_2O_5). When it is realised that a part only of the mineral constituents of feeding stuffs is assimilated by the animal, and that supplies are also needed to enable the formation of blood and bone, it is obvious that these amounts do not constitute even the minima necessary for the production of a gallon of milk. While authorities differ slightly in the quantities of minerals recommended, there is fairly general agreement that 0·7oz salt (NaCl) 1·5oz lime and 0·8oz phosphate, suffice to maintain an animal of average weight, while for each gallon of milk, approximately 0·6 oz salt, 0·65 oz lime and 0·8 oz phosphate are required.

Most concentrated foods are produced from seeds, and as such are poor sources of lime, although usually comparatively rich in phosphates ; they also tend to be very poor in chlorine, and fairly-good to good sources of potash. The following figures representing the average percentage mineral composition of some typical foods serve to illustrate this fact (see appendix tables).

TABLE 15

	Total Ash	Lime (CaO)	Phosphoric acid (P_2O_5)	Potash (K_2O)	Chlorine (Cl)
Wheat	1·7	0·05	0·86	0·60	0·08
Barley	2·6	0·07	0·84	0·57	0·12
Oats	3·1	0·14	0·81	0·55	0·07
Maize	1·3	0·02	0·82	0·40	0·07
Beans	3·2	0·18	0·88	1·28	0·03
Decorticated groundnut cake	5·8	0·20	1·30	1·50	0·03
Linseed cake	5·2	0·51	1·70	1·30	0·09
Palm kernel cake	3·8	0·30	1·10	0·50	0·16
Coconut cake	5·4	0·50	1·50	2·00	–
Pasture grass (rotational close-grazing)	2·0	0·28	0·16	0·60	0·19
Marrow-stem kale	1·9	0·43	0·12	0·55	0·21
Good meadow hay	6·2	1·00	0·43	1·60	0·37
Seeds hay	6·3	2·00	0·60	1·80	0·30

It will be seen that the foods which usually make up the production ration are badly balanced as sources of minerals ; those fed for maintenance are much better balanced and good sources of minerals generally. (In comparing the pasture herbage and kale with the others, one must remember that the former are succulent foods containing only $\frac{1}{4}$–$\frac{1}{5}$ of the dry matter present in the concentrates and hay).

It is evident that the foods fed for maintenance constitute a very important source of mineral substances, and as yields of milk increase, the amount of bulky foods is reduced with a consequent reduction in minerals. Maintenance rations for cows yielding up to 3 gallons of milk may contain 14–20lb of hay, and if of good quality, this provides 2·2–3·2 oz of CaO and 1·0–1·4oz P_2O_5, thus contributing substantially to the mineral requirements. With a reduction of the hay and other foods constituting the maintenance ration, a deficiency is likely to arise in the case of cows giving over three gallons, and it is wise to add suitable mineral mixtures to the ration, or to place mineral licks in the manger before each animal. A mixture containing finely-ground or precipitated chalk, sterilised steamed bone flour and common salt, in the proportion of 1 : 1 : 2 by weight, is suitable and 2–3lb should be mixed thoroughly with each cwt of concentrates.

While it is possible to supplement a ration in this way, there is no doubt that mineral substances are utilised far more efficiently when supplied in natural foods, and it is to this fact that home grown foods such as hay—and especially legume hay—dried grass, good silage, kale,

roots and pasture herbage owe much of their value. With the exception of hay, they are, also, to a greater or lesser extent, green foods, and good sources of carotene and hence vitamin A. Although it will generally contain little carotene, sun-cured hay provides considerable amounts of vitamin D, so that it should not be difficult to provide dairy cows with these vitamins which are so important in the case of farm animals. Cows on grass in the summer obtain an abundance, and this also applies to those fed indoors when any of the above-mentioned green foods are provided. In the case of high yielding cows, the highly concentrated ration may fail to supply sufficient vitamin A, and this may be remedied by providing a small quantity of good quality dried grass, silage or kale, while at times it may be necessary to supply 2oz of cod-liver oil per day.

A further characteristic of foods, in particular the home grown foods comprising the bulk of the maintenance ration, is of great importance, namely, the wide variation in composition brought about by conditions of growth and harvesting. When referring to average figures for the composition and nutritive value of such foods, one should realise that individual foods used may be quite different in quality, e.g., the inferior hay harvested under bad climatic conditions or in an over-ripe condition. The importance of hay of good quality has already been emphasised (p .143), becauseit forms a large proportion of the winte rration of dairy cows, and recent work has shown that inadequate feeding—low S.E. or P.E.—including the use of inferior hay, is partly responsible for the production of milk low in non-fatty solids (or solids-not-fat, S.N.F.). The natural occurrence of low S.N.F. has become more frequent during the last 20 years, especially during the war, and Rowland attributes this mainly to breeding for yield with no concern for S.N.F., and to inadequate feeding ; other causes are mastitis and period of lactation. The effects are most pronounced in January-April, i.e., after prolonged winter feeding, and also appear in July and August, especially during a drought, when pasture herbage is scarce and of poor quality.([3])

In conclusion, mention should be made of the order in which the various constituents of a ration are fed. Hay and straw are usually fed after milking. Roots, kale, silage and any foods liable to taint milk are best given 3 or 4 hours before milking, and if possible out of doors, in order to keep the byre free from odours, which are so readily absorbed by milk. The concentrates, fed dry, may be given just before milking, half the ration prior to the morning milking, the other in the evening. Similarly, the coarse fodders and roots are provided in two separate

---

[3] ROWLAND, S. J., 1946, "The problem of low solids not fat," *Dairy Industries*, Vol. II., p. 656.

amounts, hay and straw in the long condition and roots whole or sliced for young stock.

Milking cows obviously require copious amounts of clean drinking water, especially when fed indoors. Ideally a constant supply should be available in automatic bowls ; otherwise it should be offered thrice daily, the total requirement varying from about 10 to 12 gallons for cows giving 2–3 gallons of milk, to double this amount for heavy milkers. It will vary with the quantities of succulent foods consumed.

Many of the general points referred to in the case of beef cattle apply with even greater relevance to dairy cows. The stockman should be gentle in handling the cattle, and should keep careful watch for scouring and disease, while attention to general cleanliness, including grooming and dusting against ticks, lice and warbles, is of paramount importance. For outdoor cattle provision should be made for shade during very warm weather.

CHAPTER 18

THE FEEDING OF SHEEP

SHEEP are reared under a very wide range of conditions, including the poor rough grazings of the open hill, improved hill grazings, the rich pastures of the lowlands, and fertile arable land. Moreover, the systems of husbandry practised in similar areas vary considerably and, when it is remembered that over thirty breeds of sheep are kept in Britain, it is not surprising that methods of feeding and management are subject to great variation.

The main object of sheep farming in Britain is the production of meat, wool being a much less important though valuable product, and the modern public demand for comparatively small joints of good quality, coupled with the greater cost of rearing under arable conditions, has led to great changes in the breeds of sheep now popular. These fall into three main groups, the Longwools which include the largest breeds, giving mutton of rather poor quality and flavour, Shortwools including the Down breeds with much shorter wool and good quality mutton, and Mountain breeds of small-sized sheep, hardy, rather slow maturing, but giving mutton of excellent quality. Longwool and Shortwool breeds have become less popular in favour of crosses between Down and Mountain breeds (especially second crosses, i.e. (Down × Mountain) × Down), because they provide smaller joints of good quality, are more prolific than the former, and better suited to the more intensive arable conditions prevailing since 1939.

Like cattle, sheep are ruminant animals and consume the same type of foods, but cattle are reared for meat and for milk, whereas sheep are kept to produce meat and wool, ewes producing enough milk to rear their lambs. Again, cattle are fed on pasture or indoors, while in this country sheep are reared almost exclusively out of doors, mainly on growing crops. It is, therefore, very difficult to ration sheep in as logical a manner as that already applied to cattle. Indeed, the nutritional requirements of sheep have received far less attention than those of cattle, and there is little information regarding the protein requirements for maintenance or production, while there has been much conflict of opinion concerning their appetite and energy requirements. The standards now used as a guide to sheep feeding are based on those suggested by Wood, who derived them from the data given for cattle by Kellner. Wood's

standards revised by Woodman, Evans and Eden are given below[1]—

TABLE 16

Live-weight	Appetite Dry matter per week	Maintenance requirement per week		Total protein equivalent requirement for maintenance and production per week	Production requirement per lb live-weight increase
		S.E.	P.E.		S.E.
lb	lb	lb	lb	lb	lb
60	14·5	6¼	0·24	1½	1½
70	16·2	7[illegible]	0·28	1½	1½
80	17·9	7¾	0·32	1¾	1½
90	19·1	8¼	0·35	1¾	1¾
100	20·4	9	0·38	1¾	2
110	21·7	9½	0·42	1¾	2¼
120	22·9	10	0·46	1¾	2½
130	24·2	10½	0·50	1¾	2¾
140	25·5	11	0·54	1¾	3
150	26·8	11½	0·58	1¾	3½
160	28·0	12	0·62	1¾	3¾
170	28·9	12½	0·66	1¾	4
180	29·8	13	0·70	1¾	4
190	30·6	13½	0·74	1¾	4
200	31·5	14	0·78	1¾	4

These figures apply only to sheep reared under lowland conditions, and there are no standards available for hill sheep, nor for lambs weighing less than 60lb to which the surface law does not apply (Mountain wether lambs for example weigh about 40–45lb). It will be noted that the figures, except those in the last column, refer to weekly requirements, and that the total protein equivalent is stated in addition to the P.E. for maintenance. Some authorities consider that these estimates are too high, while others prefer them so because they allow a safe margin, and may be applied to the great variety of conditions under which sheep are reared.

As stated above, the bulk of food consumed by sheep consists of growing crops. These are usually of a succulent nature, e.g., grass, forage crops and roots, containing enough water to meet the needs of sheep, but in periods of drought, or whenever doubt exists as to the adequacy of natural supplies, water should be made available ; it will be taken readily by sheep in need of it. As in the case of other animals, the mineral

[1]Woodman, H. E., 1948, "Rations for Livestock," p. 78, Bulletin No. 48 of the Ministry of Agriculture and Fisheries (H.M. Sta. Office)

supply is important and, where the soil or herbage appear to be deficient, it is well to provide ground chalk, steamed bone flour, and common salt ; the latter, in the form of lumps of rock salt, should always be available. In this connection, the improvement of hill grazings by applications of lime and phosphates is important, for the better quality herbage provides more minerals than the unimproved areas. Mention might also be made of swayback and pining, two deficiency diseases associated with deficiencies of copper and cobalt respectively (see p. 34). From work carried out at King's College, Newcastle, it appears that the benefit derived from the practice of moving sheep suffering from pining to heather grazings is due to the relative richness of heather in cobalt and also copper, iron and manganese.([2])

In view of what has been said, it is evident that sheep feeding remains very much an art rather than a science, and the reader should familiarise himself with the very diverse systems of sheep husbandry practised under the varied conditions under which sheep are reared ; only a few typical examples will be considered here to illustrate how the above standards can be used as a guide to feeding, and in particular the use of concentrated foods. The descriptions which follow must inevitably include brief references to some aspects of management, and one may conveniently start with the breeding ewe.

Feeding ewes prior to and after lambing

Lowland ewes generally lamb for the first time when either one or two years old, and mountain breeds when two or three years old depending on local conditions. Lowland ewes will be fed so as to ensure slow but steady progress until the time of mating. Older ewes which have borne lambs will have had their diet severely restricted after the lambs are weaned, for example, by putting them on the poorest pastures. Subsequently they are kept in a steadily improving condition until within a few weeks of mating. At this time ewes are " flushed ", that is, suddenly introduced to a much richer diet of young pasture or seeds, rape and kale, or, if green crops are unavailable, about a pound of oats may be given. This sudden improvement in diet leads to increased ovulation and, consequently, a larger percentage of twin lambs, although this also depends on the natural fecundity of the ewe, but " flushing " is not practised in mountain flocks, where, owing to the poor grazing available, one sturdy lamb is preferred.

In-lamb ewes are wintered out of doors with little supplementary feeding. Mountain flocks are brought down to lower pastures when

[2] Thomas, Brynmor, Escritt, J. R., and Trinder, N., 1945, " The minor elements of common heather," *Emp. J. exp. Agric.*, 13, p. 93

snowstorms are imminent, and receive hay or concentrates in the most severe weather when snow completely covers the ground. It is undesirable that pregnant ewes should lose condition during the winter, and some additional food is given even on the lowlands, and especially during the second half of pregnancy. This consists of about ½ to 1 lb of hay per ewe per day and during the last month ½-1 lb of concentrated food fairly rich in protein, e.g., 2 parts each of crushed oats and bran mixed with 1 part of decorticated groundnut cake, crushed beans, or linseed cake. There are no standards available for pregnant ewes, and this is an instance where the shepherd is dependent upon his art to keep the sheep in a thrifty condition. In arable areas pregnant ewes are fed alternately on pasture and roots or forage crops, with hay and concentrates as in the above instance. Heavy root feeding must be avoided as it leads to an over-fat unhealthy condition, overgrown foetuses and loss of lambs. The feeding of hay counteracts this, while concentrates fed prior to lambing prepare the ewe for suckling. In short it is important to maintain the ewe in a thriving condition without becoming over-fat ; under feeding or unbalanced feeding, and in particular a sudden deterioration of the diet—caused for instance by a heavy fall of snow—may induce pregnancy toxaemia or " twin sickness," a condition arising in late pregnancy and highly fatal in an advanced form. The exact cause is not known, but is apparently connected with the diet ; symptoms include deranged consciousness and walking in a circle, inability to rise from the recumbent position without assistance, grinding of the teeth, blindness and coma.

Lambing may commence as early as the beginning of December in the South of England, in late January in lowland parts of Wales, and not until late in April on Highland grazings, so that the feeding of ewes with lambs will depend upon the grazing available. Ewes of medium-sized breeds weighing about 160 lb may be reckoned to give on an average 3 gallons of milk per week ; the yield will, of course, vary greatly from small mountain breeds to the large breeds and also amongst individuals. Ewe's milk is far richer than cow's milk, the average percentages of fat, protein and lactose being in the region of 7·4, 6·1 and 4·8 respectively, compared with 3·7, 3·5 and 4·6 in the latter. Because of this fact Woodman suggests that 4 lb S.E. and 1 lb P.E. be allowed for each gallon of milk.([3]) From the above table the ewe will require 12·0 lb of S.E. for maintenance and 4×3 lb S.E. for production, making a total of 24·0 lb. The protein equivalent for maintenance, added to that required for production, amounts to 3·62 lb. In meeting these requirements it is important to remember that suckling ewes have larger appetites than is indicated in

[3]Woodman, H. E., 1948, " Rations for Livestock," p. 82, Bulletin No. 48 of the Ministry of Agriculture and Fisheries (H.M. Sta. Office). Cow's milk here refers to that of the Shorthorn cow.

the above table, and may consume up to 40 lb of dry matter per week according to Wood. Assuming that the ewe is consuming 1 lb of seeds hay (ryegrass and clover), and 20 lb of thousand-headed kale daily, the following amounts of protein and energy are supplied per week. (It is assumed that lambing is early and a supply of kale available under comparatively mild conditions).

	S.E. (lb)	P.E. (lb)	D.M. (lb)
7 lb seeds hay provide	2·10	0·34	6·02
140 lb thousand-headed kale provide	14·42	2·03	22·12
	16·52	2·37	28·1

This leaves a deficiency of 24·0 — 16·52=7·48 lb S.E., and 3·62 — 2·37=1·25 lb P.E., to be supplied in a maximum of about 40–28=12 lb of dry matter, for example, by the following mixture of concentrates weekly, the daily ration being about $1\frac{1}{2}$ lb—

	S.E. (lb)	P.E. (lb)	D.M. (lb)
2 lb crushed oats	1·19	0·15	1·73
$1\frac{1}{2}$ lb crushed barley	1·07	0·11	1·28
4 lb flaked maize	3·36	0·37	3·56
2 lb bean meal	1·32	0·39	1·71
1 lb linseed cake	0·74	0·25	0·89
$10\frac{1}{2}$ lb concentrates	7·68	1·27	9·2

When kale is not available, mangolds are excellent for ewes with lambs, but do not supply as much protein as kale. They are also very useful when supplies of other roots and kale are at an end, and it is too early for young grass or seeds. When young grassland herbage of good quality is available, for example, from early grass leys, no supplementary feeding is necessary, and the reader might confirm this for himself using the same reasoning as that applied in Chapter 17, and assuming the above capacity for dry matter. From the practical point of view, the problem resolves itself into correct stocking of the pastures, which vary greatly in productivity. The rich Romney Marsh pastures may carry six ewes per acre, the best leys three ewes with their lambs, and average pasture two ewes with two or three lambs per acre. Many pastures carry only one sheep per acre, while as many as five to ten acres of poor mountain grazings are required to support one small ewe. Sheep tend to select the finer grasses and clovers, and it is sound practice to include a few store bullocks in order to secure more even grazing and prevent the development of coarse tufted growth.

Frequent change of pasture is essential to prevent fouling and infestation of the lambs with internal worms, and dosing with phenothiazine at 6–8 weeks old, and at two consecutive monthly intervals, is now resorted to as a routine measure.

Fattening

The problem of feeding for meat production is one which may be considered from several aspects, depending upon the aim of the farmer, the demand for and prices of meat, and the foods available. A few lambs may be fattened rapidly and sold as baby lamb. Others are fattened while running with their dams, which are later reserved for future breeding, while in some cases both lambs and ewes are fattened together. None of these systems involves a store period ; the lambs make rapid growth and fatten simultaneously. Many lambs are reared as stores until they weigh 60 to 90lb, when as tegs or hoggs they are fattened and sold at a live-weight of about 100 to 120lb. For our present purposes two of the above systems will be considered, namely, the fattening of lambs without a store period and the fattening of tegs.

Lambs are sold fat when they weigh up to 80lb, the earliest at 10 weeks old, and others when 3–4 months old. They may be fattened on grassland or forage crops. In the latter case the ewes and lambs are folded on the green crop and moved on to a new fold each day. In addition they receive concentrates, which the lambs begin to eat when about 2 weeks old, and it is desirable to provide a special mixture for the lambs. This is accomplished with the aid of " creeps," i.e., hurdles with adjustable apertures allowing only the lambs to pass and receive their concentrates in troughs placed in the next fold. In this way, when they start to eat green food, they also receive the best of the forage together with their concentrates, which consist of such foods as crushed oats, flaked maize, linseed cake, crushed peas or beans and bran. The first four, in equal proportions by weight, form a suitable mixture, the amount being increased gradually until about 1 lb per head is consumed daily. The ewe receives a separate supply of concentrates, and the feeding varies according to whether she is to be kept for breeding or fattened along with the lambs. In the former case, the amount of concentrates fed after lambing is decreased as soon as the lambs commence to eat their mixture, so that when the lambs are sold, the ewes receive no concentrates, and are transferred to much poorer forage or to poor pasture to arrest the flow of milk. Their food is restricted in quality and quantity until they are again flushed prior to mating. Ewes to be fattened with their lambs may be members of " flying flocks," i.e., flocks formed by buying ewes drafted from breeding flocks. These are ewes not required for breeding and usually past their best for this purpose,

but in sound breeding condition. They are fed with their lambs in a similar manner to the above but rather more generously, and receive concentrates until they too are sold fat with their lambs or soon afterwards.

In Wales, the fattening of Welsh Mountain wether lambs on rape or aftermath is widely practised. The lambs weigh some 40–45 lb only in October, and are sold after a period of 10–12 weeks weighing about 60–65 lb in February-March. An interesting feature of the system is the need for coarse herbage to counteract the tendency to scour on young rich rape, and the lambs usually graze the former night and morning, and the latter during the day. Alternatively, they may have free access to pasture while grazing the rape.

It will be realised that not all lambs are fattened and sold, for ewe and ram lambs are required to carry on the flock and form new flocks. They are fed with their dams on grass or forage crops, and weaned at 3 to 4 months old. While ram lambs may receive special feeding, ewe lambs are less generously fed than if they were to be fattened. As ewe tegs they are wintered on lower ground or on a lowland farm, and kept in more or less store condition until at about 19 months old, as " gimmers " or "theaves," they are mated to lamb at 2 years old.

The above description serves to emphasise a point made at the beginning of the chapter, namely, that it is very difficult, if not impossible, to consider some aspects of sheep feeding from the point of view of feeding standards. Nevertheless, these may be employed when one considers the fattening of lambs, which, after passing through a store period and still retaining their lamb teeth, become known as tegs, hoggs or hoggetts in the autumn. Mountain flocks are important sources of lambs for this purpose, for lambs which cannot be fattened on the poor herbage available are sold as stores into lowland areas, and fattened on pastures and rape. They are mainly wether lambs, i.e., castrated males, together with ewe lambs unsuitable or not required for breeding. Crosses between Mountain ewes and Longwool rams are also in great demand, e.g., Cheviot × Border Leicester, while many other types of store are available. Their weight naturally varies according to the breed or breeds from which they are produced. Their treatment will have been rather similar to that of the ewe lambs mentioned above and, after keeping in healthy growing condition without fattening, they may be assumed to have attained a live-weight of about 80 lb. They are fattened during the winter in about 3 months, and gain about 30 lb in weight, making an average weekly gain of 2 to $2\frac{1}{2}$ lb. From the table of nutrient requirements, a teg of this weight gaining 2 lb weekly requires $7\frac{3}{4}$ lb S.E. for maintenance, and $1\frac{1}{2}$ lb S.E. per pound live-weight increase, in this case $1\frac{1}{2} \times 2 = 3$ lb, making a total of $10\frac{3}{4}$ lb. The total P.E. required will be $1\frac{3}{4}$ lb. The food available during

the winter consists of hay, roots or forage crops such as kale, and concentrated foods. It may be assumed that 3 to 4lb of hay and 80 to 90lb of kale or roots are consumed per week, providing the following quantities of starch and protein equivalents and dry matter.

	S.E. (lb)	P.E. (lb)	D.M. (lb)
90 lb of swedes will provide ...	6·57	0·63	10·35
3½ lb good red clover hay will provide	1·33	0·25	2·92
	7·90	0·88	13·3
Total requirements	10·75	1·75	17·9
To be supplied by concentrates ...	2·85	0·87	4·6

Suitable concentrated foods include cereal products such as barley, oats, dried brewers' grains and maize, with protein-rich cracked peas or beans, and oil cakes, e.g., linseed, cotton-seed and groundnut cakes. The following would provide the additional nutrients required—

	S.E. (lb)	P.E. (lb)	D.M. (lb)
2 lb dried brewers' grains provide ...	0·97	0·25	1·79
3 lb flaked maize	2·52	0·28	2·67
3 lb dec. groundnut cake	2·19	1·24	2·69
8 lb mixture	5·68	1·77	7·15
4 lb mixture	2·84	0·88	3·6

Four pounds per week, slightly more than ½lb per head daily, is allowed, and the dry matter is well within the animal's capacity. It will be noted that the ratio between the total protein and starch equivalents provided (1·76 to 10·74) is approximately 1 : 6, and meets the requirements of young animals still making considerable growth as well as fattening. The ratio may be widened gradually, for example, by increasing the proportion of maize, until in the third month of fattening it becomes 1 : 8. It is also worth noting that the concentrates are fed in troughs, so that individual animals may consume more or less than the above amounts. This will also apply to the amount of other foods eaten, and individual live-weight gains vary from 1 to 3lb per week. The food requirements will, of course, increase as the sheep increases in live-weight during the fattening period.

It is important that the hay provided should be leafy and of good quality, preferably leguminous, for stemmy material is rejected and wasted. Lambs brought from grassland areas must be introduced gradually to forage crops and roots to avoid scouring, especially in early winter.

It is best to put the lambs on pasture and to carry roots to them, or to allow access to the root area for short periods. It may be necessary to slice roots for tegs in process of changing their teeth. If an equal weight of kale is consumed instead of roots, much more protein is provided, in the case of marrow-stem kale 1·26lb or double that supplied by swedes, and less need be provided in the concentrated foods. Young rich grassland herbage too provides abundant protein and is itself excellent for fattening sheep and lambs. If poor in quality, or restricted in amount, it may be supplemented with hay, roots or forage crops and concentrates.

Whatever system of rearing and feeding is employed, whether on grass or arable land, it is imperative that sheep be kept as healthy as possible, for like other farm stock, they are subject to numerous troubles and will not thrive if allowed to suffer in any way. Drenching against stomach worms has been mentioned, and dipping is another routine practice necessary to control infestation with keds, ticks, scab mites, lice and the attack of blow flies.

CHAPTER 19

THE FEEDING OF HORSES

THE purposes for which horses have been bred are many and varied, and modern horses include such divergent types as the heavy Shires and Clydesdales, the Thoroughbred, Hunter and Polo ponies, and many smaller ponies used for riding, light draft purposes and in the mines. From the farmer's point of view horses are used mainly for draft purposes and for riding, and farm horses only will be considered here.

General requirements of the horse

The horse is a non-ruminant, and has a smaller stomach capacity in relation to size than cattle and sheep, but the caecum and colon of the large intestines are much larger relative to those of other farm animals, and enable the horse to deal with considerable quantities of roughage. With few exceptions, therefore, horses, cattle and sheep eat similar types of food, although rather more attention is paid to the horse in this respect. It is important that the hay given should be hard but well seasoned, and free from mustiness or moulds. Good meadow hay, or that made from ryegrass or timothy, is best. Leafy hay tends to be dusty and apt to cause respiratory troubles ; leguminous hay, because of the leafy clover, etc., is difficulty to dry and liable to become mouldy, causing " broken wind " in horses and abortion in pregnant mares. Oat straw is a suitable fodder, and in some localities bean straw is used, but wheat straw is valueless, its net energy being less than that required to digest it. Oat straw is useful for replacing hay for idle horses, and in moderate amounts for horses doing light or medium work, but is not fed to horses doing hard continuous work. It is customary to feed 4–6 lb of the coarse fodders in the form of chaff, and in Wales chaffed oat sheaves are often fed to working horses.

Of the cereals, the oat grain is pre-eminent, barley and maize are suitable when fed carefully and in small quantities, and wheat too is used in small amounts, but is liable to cause digestive disturbances and is not popular, while rye is unsuitable. Among leguminous grains beans are excellent but, as in the case of oats, grain a year old is best, for fresh grains cause digestive trouble. The coarse fodder and grains are fed together, for which purpose hay and straw are chaffed, and the grains bruised or crushed and well mixed with the fodder. This aids mastication, prevents bolting of the grains, and crushing facilitates the action of the digestive juices. The mixed " chop " is also a convenient way of carrying a feed

into the field for feeding mid-day from a nose-bag, and it enables the horseman to control the amount of coarse fodder.

At least three feeds a day should be given, and it is quite wrong to expect a tired horse to consume a large meal after a long period of abstention; this leads to overburdening of the limited stomach capacity and causes indigestion. The morning feed should be given a considerable time—say $1\frac{1}{2}$ hours—before work commences, and a second meal when the morning work ceases, at least an hour being allowed for each. A third feed is given in the evening, and a portion of the fodder is fed long so that it can be eaten at leisure from the rack. Water must be offered as often as possible, preferably before meals, and never in large quantities immediately afterwards. When a horse is overheated and thirsty, about half a bucketful of lukewarm water is offered, and more given at intervals to quench the thirst. A large volume of cold water must not be given at such times. Rock salt should always be available in the manger.

Before considering feeding standards, attention is drawn to several points of difference between horses and other farm stock, which have a bearing on nutrition. The most important is the nature of the "production" in each case, for cattle, sheep, pigs and poultry are reared for meat and such products as milk, wool and eggs, whereas horses are kept primarily for work. In the case of the other animals fattening is important, but it is very undesirable to allow horses to become too fat, the object being to keep them in healthy hard condition. Horses are fed for energy production, and consequently carbohydrate-rich foods are of primary importance, much less attention being paid to protein than in the case of other animals. The protein necessary for normal metabolism must, of course, be provided but, as will be seen later, very simple rations usually provide an abundance, and protein-rich foods are necessary in comparatively few circumstances. Although many are suitable, oil cakes play a very limited part, and are chiefly used to encourage ailing animals to eat ; for this purpose a pound or two of linseed cake is useful, preferably crushed, as oil cakes tend to be rather hard. In general, oil cakes are too laxative for working horses. Another food which has a special use is bran, which is often given in the form of a mash on Saturday evenings to prevent ill effects such as constipation and stiffness of the limbs of horses idle over the week-end.

Horses also differ from other stock in that no " production " is required of them during the first $2\frac{1}{2}$ years, except, of course, that inherent in normal growth ; other animals may be fattened and produce meat and/or milk when comparatively young. In addition, horses give longer service and remain in useful working condition for ten years or more, whereas other animals are not kept for many years except for breeding.

Feeding standards

In attempting to apply these to the feeding of horses, one is at once beset by several difficulties. It is remarkable that comparatively little experimental work has been done with horses ; in consequence, the energy requirements have to be considered in terms of the starch equivalent values determined for cattle, which do not necessarily apply with equal relevance to horses. Then again it is impossible to assess the energy expended in a given type of work with accuracy, for measurements carried out by placing a dynamometer between a horse and plough, for example, will have little application to other conditions. The energy expended will vary with the slope of the ground, the soil texture, the type of implement and even the animal itself, since two different horses will exert different amounts of energy in doing the same work. It is because of this difficulty that work is assessed as light, medium or heavy, terms which can be nothing more than rough estimates, depending more on the speed rather than the duration of the work. Thirdly, farmers seem to have far less idea of the live-weights of their horses in comparison with other animals, which, after all, are for many purposes sold on a live-weight basis. In rationing one must use such estimates as are available for horses of various types. Heavy horses such as the Shire weigh about 18 to 20 cwt, and light farm horses about 13 cwt ; average heavy horses may be assumed to weigh about 15 cwt. Bearing these difficulties in mind, one may proceed to discuss assessments of energy and protein required with reference to some typical rations for working horses.

The maintenance requirements of horses are not very different from those of cattle. Actually a horse requires rather less energy for maintenance than an ox of the same live-weight and, as stated in Chapter 15, the data given for the maintenance protein requirements apply to cattle and horses. The difficulty of assessing the requirements for work has already been mentioned. Some authorities allow different amounts of starch equivalent for light, medium or heavy work, while others consider that the arbitrary nature of such assessments does not warrant this procedure. Linton's estimates may be stated very concisely as follows[1]—

	S.E. (lb)	P.E. (lb)
Daily maintenance of a 1000-lb horse	5·0	0·5
For each 100 lb body weight difference add or subtract	0·3	0·05
For every hour of hard work (per 1000 lb live-weight)	1·0	0·15

The addition or subtraction of S.E. and P.E. are based on Rubner's Surface Law, while " per hour of work " applies to actual work performed,

[1]Linton, R. G. and Williamson, G., 1943, " Animal nutrition and veterinary dietetics " pp. 360 and 361, (Green and Son, Edinburgh.)

no attempt being made to define the ardour of the work. Linton further states that " the total dry matter of the diet should be not less than from $1-1\frac{1}{2}$ per cent of the animal's live-weight," and suggests 1 to 1·25 per cent for idle horses, and 1·5 to 2 per cent for working horses. On this basis a 1,600 lb horse requires $5{\cdot}0+(0{\cdot}3\times 6)=6{\cdot}8$ lb S.E. for maintenance, and $0{\cdot}5+(0{\cdot}05\times 6)=0{\cdot}8$ lb P.E.; the production requirements depend on the actual number of hours of work performed.

It will be seen, therefore, that despite many difficulties, it is possible to apply feeding standards to the feeding of horses. In doing so, however, one should always bear in mind that the extension of the system worked out for cattle involves many assumptions, and is at best a guide to rationing under average conditions. The successful feeding of horses in order to keep them in hard healthy condition calls for very careful management and constant attention on the part of the horseman.

Feeding in practice

In practice the procedure adopted is simple, probably more so than in the case of other farm stock. The coarse fodders provide the bulk of the maintenance requirements, while energy is provided in concentrated foods and, as stated above, the protein requirements need comparatively little attention. Hay and oats are the traditional foods of horses, and excellent results may be obtained by using these two foods alone, or in conjunction with a little straw. A common ration consists of about 16 to 18 lb of hay and 12 lb of oats, which provide the following amounts of starch and protein equivalents and dry matter—

	S.E. (lb)	P.E. (lb)	D.M. (lb)
18 lb good meadow hay provide ...	6·66	0·83	15·4
12 lb oats	7·14	0·91	10·4
	13·80	1·74	25·8

One may now consider how far this meets the requirements of an average farm horse of 1,450 lb live-weight, i.e., about 13 cwt. Using Linton's data, the maintenance requirements are $5{\cdot}0+(0{\cdot}3\times 4{\cdot}5)$ or 6·35 lb S.E., and $0{\cdot}5+(0{\cdot}05\times 4{\cdot}5)$ or 0·73 lb P.E. The above ration supplies $13{\cdot}80 - 6{\cdot}35=7{\cdot}45$ lb S.E. and $1{\cdot}74 - 0{\cdot}73$ or 1 lb P.E. for production. For every hour of hard work 1·0 lb S.E. and 0·15 lb P.E. are required per 1,000 lb live-weight, so that a 1,450-lb horse requires 1·45 lb S.E. and rather less than 0·22 lb P.E. The starch equivalent available for production suffices for $7{\cdot}45 \div 1{\cdot}45$ = approximately 5 hours work and the protein equivalent $1 \div 0{\cdot}22$, again 5 hours approximately. The capacity

of the animal for dry matter would amount to 1·5 to 2 per cent of 1,450 lb, approximately 22 to 29 lb and the above ration provides about 26 lb.

This very simple ration may be varied by replacing some of the oats by beans, and this is particularly desirable when foods poorer in protein are fed, for example, when some hay is replaced by straw, and oats by maize. If, for instance, a more typical ration such as 12 lb of hay and 6 lb of oat straw is fed, the following amounts of S.E. and P.E. are provided—

	S.E. (lb)	P.E. (lb)	D.M. (lb)
12 lb good meadow hay will provide	4·44	0·55	10·3
6 lb oat straw will provide	1·20	0·05	5·2
	5·64	0·60	15·5
whereas 18 lb of the hay would provide	6·66	0·83	15·4

Thus substitution of some hay by straw leaves a deficiency of S.E. and a relatively greater deficiency of P.E., both of which can be made good by replacing some oats by maize and beans, the protein in the beans being sufficient to compensate for the poverty of the oat straw and maize in this constituent. The replacement of oats by other foods involves an important principle, namely, that replacement should be on an "oat equivalent" basis, not a pound for pound basis, which in the past led to dissatisfaction with such oat substitutes as maize. Oats, maize and beans have respectively the following starch equivalents : 59·5, 77·6 and 65·8. On this basis 1 lb of oats is equivalent to $59{\cdot}5 \div 77{\cdot}6$ lb of maize, and $59{\cdot}5 \div 65{\cdot}8$ lb of beans, namely 0·77 and 0·90 respectively. Assuming that 6 lb of oats are being fed instead of 12, 4 lb of the remainder would be replaced by $0{\cdot}77 \times 4 = 3$ lb (approximately) of maize, and 2 lb by $0{\cdot}90 \times 2 = 1{\cdot}8$ or approximately 2 lb of beans. The modified ration would be—

	S.E. (lb)	P.E. (lb)	D.M. (lb)
12 lb good meadow hay	4·44	0·55	10·3
6 lb oat straw	1·20	0·05	5·2
6 lb oats	3·57	0·46	5·2
3 lb maize	2·33	0 23	2·6
2 lb beans	1·32	0·39	1·7
	12·86	1·68	25·0

The original ration provided rather more nutrients because the coarse fodder consisted entirely of hay and, as previously stated, straw is only fed to horses doing comparatively light work. Much depends on the type of work, and oats or their equivalent in concentrates may be as low as

7 lb for light work and up to 20 lb for heavy work. In Scotland, where horses are generally worked hard, about 4 lb more oats are fed for a given type of work than in the Midlands and South of England, where the speed of the work is usually lower. Oats generally comprise the bulk of the concentrates, but up to 50 per cent may be replaced gradually by suitable mixtures of such foods as barley, maize, wheat, bran and beans fed on an " oat equivalent " basis. Succulent foods are beneficial, and 10–20 lb of swedes, turnips, mangolds or carrots may be offered.

The undesirability of allowing horses to become fat has already been emphasised. For this reason concentrated foods are severely restricted during periods of idleness, and the ration may be little more than is necessary to meet maintenance requirements. Restricted feeding is necessary to avoid digestive disturbances, which would occur if heavy feeding were continued. It is usual to restrict the concentrates fed on Saturdays and Sundays and, as previously mentioned, a bran mash is frequently given to horses facing an idle week-end.

During the summer, idle horses will thrive on pasture of good quality without additional feeding, and hay may be omitted entirely, but as the season advances, and the herbage deteriorates in quality, hay and/or oats must also be given, the amount depending on the quality of the herbage and condition of the horse, which must be carefully watched and not allowed to deteriorate, for the approaching harvest operations will make heavy demands on the animal's vitality. Working horses at pasture may receive as little as 6 lb of oats when doing moderate work. It should be remembered that horses graze very unevenly and should graze along with other stock.

Like all farm animals, horses derive considerable benefit from green herbage, and the health-giving sunshine and exercise which accompany grazing. Green succulent food, or roots, are of special advantage for pregnant mares, especially when leguminous forage from rich soil is available, for brood mares have comparatively high protein and mineral requirements. They receive a more generous allowance of concentrates than is demanded by the conditions of work, for example, a few extra pounds of oats or their equivalent in beans or linseed cake, and very bulky foods such as oat straw are omitted. A daily allowance of an ounce or so of sterilised meat and bone meal, steamed bone flour or fish meal may also be given. Moderate exercise is essential, and brood mares are frequently worked throughout the period of pregnancy, but the work must be of a light nature during the last 5 months. The aim is to maintain a healthy condition, avoiding excessive fatness or leanness, which again calls for skilful feeding and management. This also applies to many other aspects of horse management which will only be mentioned here,

namely, the rearing of foals, and the many diverse types of light horses and race horses. In fact horses probably need more personal attention than other farm stock. They should be housed in well-ventilated, well-drained quarters free from draughts and, as in the case of other animals, a careful watch kept for any signs of ill health or general unthriftiness. Grooming deserves special mention, for at present there is a tendency to neglect this most important aspect of management to the general detriment of the horse. It should be carried out regularly and thoroughly.

CHAPTER 20

THE FEEDING OF PIGS

General considerations

The pig differs from ruminant animals and the horse in possessing a greatly restricted digestive system. Nevertheless, pigs are able to deal with a larger bulk of dry matter in relation to their weight than other farm animals, and consequently make very rapid growth. In fact the pig is able to put on 1lb of live-weight with less food than other farm animals, and young small pigs are able to do so with less food than older and larger animals. It is important to realise, however, that the pig has no storage capacity for fibrous foods, nor the ability to digest fibre, which has to be carefully restricted. In other words pigs require the dry matter of their food in a highly digestible and concentrated form. When this condition is met, they use starch and sugars more efficiently than ruminants, because these constituents are not broken down by bacteria into useless products such as methane (p. 53).

Pigs may be fed out of doors, indoors or, as is very desirable, by a combination of both systems. In the former case they consume a great variety of animal and vegetable foods, and obtain abundant supplies of minerals and vitamins, whereas these may be deficient when fed indoors on a less varied diet. In either case the bulk of the food consists of concentrated foods of a starchy nature such as barley meal, ground oats and wheat, maize meal, flaked maize and milling offals. In order to provide the necessary protein, white fish meal, meat meal, meat and bone meal and dried blood are used, also meals prepared from beans, peas, palm kernels, groundnuts and soya-beans. When meals of animal origin are used, a supply of minerals is assured, and the special value of fish meal is due to this fact and the provision of high quality protein. The inclusion of white fish meal up to 10 per cent of the ration supplies abundant minerals. Milk products and meat and bone meal are also excellent sources of high quality protein and minerals. Where such foods are unavailable, or where fish meal is considered an undesirable food, it is possible to meet the protein requirements by including protein-rich foods of vegetable origin, such as soya-bean or decorticated groundnut cakes and meals. Under such conditions the ration may be deficient in minerals, particularly calcium, sodium, iron and chlorine, and a simple mineral supplement should be provided, for example, 3 parts of ground chalk to 1 part of common salt, making up 2 per cent by weight of the ration.

Alternatively, ground chalk, steamed bone flour, common salt and wood and coal ashes are placed in separate boxes or troughs from which the pigs take what they want. Small amounts of wood ashes and coke appear to be useful and aid digestion.

It is always advantageous to include some amount of succulent or green food in the daily ration, for this helps to maintain health by supplying vitamins and minerals and preventing constipation. Such foods include kale, grass, silage, dried grass and lucerne meals, and they also supply iron. Sow's milk is deficient in iron, and young suckling pigs, although born with a reserve in the liver, may develop a deficiency when 4–6 weeks old, causing scouring and anaemia with paleness of the skin. This condition rarely occurs when the young pigs and their dams are fed out of doors, but may be serious under indoor conditions, when steps must be taken to prevent or remedy the iron deficiency. Turves obtained from soil rich in iron are placed in the sow's pen, or the young pigs may be dosed daily with a teaspoonful of a solution of cane molasses containing about 2 per cent of ferrous sulphate and a trace of copper sulphate. Small amounts of yeast included in the rations of farrowing sows have been found to have a beneficial effect both on the sows and on their litters. It will be remembered that yeast is a rich source of vitamins of the B complex.

When the feeder has assured himself that the nutritive requirements have been met, he must also pay some attention to the condition in which the food is to be given to pigs. Because pigs are unable to digest fibre, foods containing fair amounts (e.g., oats) must be very finely ground, and for young pigs all concentrates should be ground, whereas whole grains may be given to sows provided that they are soaked thoroughly to aid mastication and digestion. In the wet system of feeding all concentrates are soaked in water, while advocates of dry feeding consider that, when allowed to consume unrestricted amounts of water, fattening pigs tend to become too fat and young pigs " pot-bellied ". Many feeders provide the food by mixing with twice its weight of water, some give the meal dry or in the form of cubes and allow access to water, while others combine both systems of feeding. At all events sows must have free access to water especially when they are suckling young.

It is generally worth cooking potatoes for pigs ; this increases their food value very considerably. Raw tubers are liable to cause digestive disturbances, although small quantities may be consumed with relish. With the exception of swill, which by law must be boiled prior to feeding, cooking is not justifiable in the case of other foods. It is advantageous, however, to give warm food to young or ailing pigs and farrowing sows especially under cold damp conditions.

In Chapter 14 the effect of food on the quality of the product has been discussed, and deserves special attention in the case of the pig, whose carcass can be affected to a greater extent than those of other farm animals. The fat should be firm and suitably proportioned to the quantity of bone and lean meat. Since carbohydrates tend to produce body fat which is more saturated than that obtained from the fat or oil in the food, foods rich in oil must be fed in limited amounts. Linseed, rice, maize and maize germ meals, and other foods containing considerable amounts of unsaturated oils must be restricted, especially during the last 3 or 4 weeks of fattening and, for similar reasons, "extracted" meals are preferable to those prepared by other processes (p. 97). White fish meal contains not more than 6 per cent of oil (and 4 per cent of salt), and is less prone to produce soft or tainted fat than inferior fish meals. Although no taint is detected when fed in moderate amounts, it is usual to reduce the fish meal during the last three weeks of fattening, and to exclude it altogether for the last ten days. Barley meal and boiled potatoes are the best foods for the last stages of fattening, and beans, peas and milk also produce firm fat.

Pigs receive their food twice or thrice daily, and feeding should be punctual. Alternatively, self-feeders may be used for dry meals or cubes as they economise labour and ensure a more even distribution of food. All troughs and receptacles must be kept clean to prevent uneaten food turning sour. The conditions of housing are of prime importance, and the surroundings should be roomy, easy to clean, well ventilated and sunny. The pig suffers more than other farm animals under cold damp conditions, which may lead to sickness and waste of food in maintaining the relatively high body temperature. Pigs are by nature clean in their habits, and deserve far better surroundings than those allotted to them in the past. Much attention has been given to this aspect of pig-keeping in more recent years. (See Bulletin No. 32 of the Ministry of Agriculture and Fisheries).

Feeding standards

As in the case of cattle, sheep and horses, the requirements of pigs have been expressed in terms of starch and protein equivalents. The data were mainly derived from investigations carried out at Cambridge by Wood using the animal calorimeter and the comparative slaughter method. The energy required for maintenance was determined by studying the basal metabolism of pigs of different live-weights, i.e., the heat evolved by the animal at rest and without food, and adding to this the energy necessary to enable the pig to move about under conditions of good

management. Wood expressed the maintenance requirements in terms of net energy and starch equivalent.

As indicated in Chapter 15, the protein required to maintain an animal can be calculated from the nitrogen voided in the urine, and does not differ appreciably for different species of animals of equal weight. Consequently, the figures given apply equally to cattle, horses and pigs. Despite the fundamental importance of such investigations and the need for their extension, it will become apparent in the following discussion that, for our present purpose, no advantage is to be gained from a detailed consideration of either the energy or protein required for maintenance.

It must also be admitted that it is difficult to determine the production requirements of pigs, because they are fattened while making rapid growth, and much work remains to be done before their requirements can be gauged with accuracy. The production requirements for combined growth and fattening may be stated approximately as follows, the protein being expressed as a ratio between the total starch and protein equivalents for maintenance and production as in the case of cattle (p. 128).([1])

Age in months	2	3	4	5	6	7	8	12
lb S.E. per lb live-weight increase	0·5	0·6	0·7	0·9	1·2	1·4	1·8	2·4
Total P.E. : total S.E.	1 : 4·5	1 : 5	1 : 5·5	1 : 6	1 : 7	1 : 8	1 : 9	1 : 9

It is evident that the proportion of protein-rich to starchy foods decreases with age, for the ratio P.E. : S.E. is 1 : 4·5 at the age of 2 months and only 1 : 9 at 8 to 12 months. When a sow is rearing young, however, the production of milk necessitates a more generous protein ration, and the ratio becomes 1 : 5 again.

Rationing in practice

Although the requirements of pigs may be stated in the above manner, it is usual in practice to use a simpler procedure based on the fact that barley and the mixed meals generally used have starch equivalents of 67 to 70. As indicated at the beginning of this chapter the bulk of the ration consists of foods rich in starch, and the protein requirements are met by including about 10 per cent of white fish meal or other suitable protein concentrate, supplemented if necessary by mineral mixtures.

Furthermore, because pigs intended for pork or bacon make rapid growth and fatten simultaneously, and are slaughtered before they are

[1] WATSON, J. A. S., and MORE, J. A., 1945, " Agriculture. The science and practice of British farming," pp. 501, and 502 (Oliver and Boyd)

fully grown, their maintenance and production requirements are not considered separately : instead, the total requirements are stated in terms of meal or " barley equivalent " and it is necessary to know the amounts of various foods equivalent to one pound of barley meal. Some typical examples are given below(2)—

	lb
Milk (skim)	8·3
Whey	12·0
Young grass	6·5
Kale (marrow-stem)	7·7
Potatoes (steamed)	3·4
Mangold	10·3
Swede turnip	7·3
Middlings (fine)	1·1
Middlings (coarse)	1·3
Maize meal	0·9
Oats (finely ground)	1·2
Coconut cake meal	1·1
Groundnut cake meal (undec.) ...	1·2
Linseed cake meal	1·1
Milk (dried skim)	0·9
Milk (dried whole)	0·6
Soya-bean meal (extracted)	1·1
Fish meal (white)	1·2

In addition, the following meals are equivalent weight for weight to barley meal : rice, rye, wheat, bean, palm-nut kernel, extracted decorticated groundnut, meat and meat and bone ; also maize gluten feed and dried buttermilk.

It is useful to remember that the food requirements for fattening are met by feeding approximately 1 lb of meal per month of age, and the amount required for pigs of different weight when fully fed may be stated as follows(3)—

Live-weight (lb)	50	100	150	200	250
Meal (lb) ...	2·5	4·25	5·25	6·75	7·5

It will be noted that whereas a pig weighing 50 lb consumes 5 per cent of its live-weight of meal, this falls to 3 per cent in the case of a 250 lb animal. The economic optimum rations for pork and bacon pigs may be 10 and 20 per cent respectively below these figures. A further important

[2] HALNAN, E. T., and GARNER, F. H., 1946, " The principles and practice of feeding farm animals," p. 73 (Longmans, Green and Co.)

[3] WATSON, J. A. S., and MORE, J. A., 1945, "Agriculture. The science and practice of British farming," pp. 680 and 681 (Oliver and Boyd)

consequence of the fact that most meals used have starch equivalents of about 70 is that they may replace one another in reasonable amounts without upsetting the starch equivalent of the ration.

Having stated the requirements of pigs of varying live-weight in terms of barley meal equivalent, it remains to consider mixtures of meals for different classes of pigs bearing in mind a suitable ratio between the starch and protein equivalent.

In-pig and nursing sows, and piglings

A number of in-pig sows may be kept on pasture or in covered yards. In either case they should receive succulent foods, in summer grass and leguminous crops, in winter kale, cabbage, silage, potatoes or swedes. Sows will consume about 20–25 lb of such foods daily. The amount of meal required will depend on the nature of these foods, the amount consumed or the period of grazing allowed, and the condition of the sow. It may vary from 2–6 lb or more daily. About half the meal equivalent required may consist of succulent green food, the remainder being made up of $2\frac{1}{2}$ to 3 lb of a mixture such as the following—

40 lb barley meal giving	28·6 lb	S.E. and	2·92 lb	P.E.
35 lb fine middlings giving	24·2 lb	,, ,,	4·24 lb	,,
10 lb flaked maize	8·4 lb	,, ,,	0·92 lb	,,
10 lb white fish meal giving	5·9 lb	,, ,,	5·30 lb	,,
5 lb extracted soya-bean meal giving...	3·2 lb	,, ,,	1·92 lb	,,
100 lb mixture giving	70·3 lb	S.E. and	15·3 lb	P.E.

Actually the protein allowance is a generous one, for a ratio of P.E. : S.E. of 1 : 5 suffices at this stage, and a mixture with a wider range could be made by replacing some of the barley with maize meal and reducing the amount of fish meal—

20 lb maize meal giving...	15·5 lb	S.E. and	1·52 lb	P.E.
25 lb barley meal giving	17·9 lb	,, ,,	1·83 lb	,,
30 lb weatings giving	20·6 lb	,, ,,	3·78 lb	,,
20 lb bean meal giving	13·2 lb	,, ,,	3·94 lb	,,
5 lb fish meal (white) giving	3·0 lb	,, ,,	2·65 lb	,,
100 lb mixture giving	70·2 lb	S.E. and	13·7 lb	P.E.

The amount of meal given will depend on the nature and quality of the succulent food, the aim being to build up sufficient bodily reserves to provide for suckling without producing excessive fat. The quantity of food is increased gradually until the time of farrowing approaches, when

the sow receives 6 to 8 lb of meal equivalent, mainly in the form of meal, with a small amount of green food to keep the ration laxative. Some feeders give warm bran mash at this stage to which milk may be added. The mash is continued for a day or two after farrowing when little food is taken, and gradually replaced by a meal mixture such as the first given above. The amount consumed is increased to 10–12 lb or more depending on the size of the sow and her litter, and a little green food is provided. It may be noted here that sow's milk contains on an average more fat, protein and ash but less sugar than cow's milk. The following figures represent the percentage composition of sow's milk ([4]) and cow's milk (in parenthesis): Fat 4·55 (3·71), sugar 3·13 (4·70), proteins 7·23 (3·05), ash 1·05 (0·76).

It is of great importance that an abundance of calcium is assured, for the sow will require about 2 oz of lime (CaO) daily. While 5–10 per cent of fish meal meets this requirement, replacement by such foods as soya-bean meal or decorticated groundnut cake may cause a deficiency unless supplemented with minerals as described earlier in the chapter. It is important to see that the sow gets plenty of exercise, and the young pigs benefit by running in the fresh air and sunshine.

When about 3 weeks old, young pigs will eat a little meal and do best when allowed a separate supply rendered inaccessible to the sow by protecting small troughs with narrow bars. The mixture should be fairly rich in protein and minerals. Weatings, alone or mixed with barley meal and flaked maize, may be offered first and fish meal added gradually until it comprises 10 per cent of the mixture. Weaning takes place at ages varying from 7 to 12 weeks, preferably at 8 weeks old, when the piglings are consuming up to 2 lb of meal daily given in three feeds. Thereafter they will make good growth on 2–2½ lb of meal together with green food, which they may obtain by running in large groups on pasture. Skim milk is excellent for young pigs, and may be given as the first food in addition to the sow's milk, and later used with meals such as weatings and barley meal.

Pork and bacon pigs

While it is outside the scope of this book to discuss the main features of pork and bacon pigs, it may be indicated that there are many points of similarity in the standards laid down for the ideal types, (see Ministry of Agriculture, *Report on Marketing*, No. 12, p. 32). Generally speaking pork pigs are shorter in the body and more stocky than bacon pigs. The former are required to develop broad well-covered backs and heavy hams

[4] ELSDON, G. D., and WALKER, G. H., 1942, "Richmond's Dairy Chemistry," p. 79 (Charles Griffin and Co. Ltd., London)

at a live-weight of about 100 lb, whereas the latter are killed at double this live-weight to give long, deep sides and well developed hams with a high proportion of lean meat. Essentially, therefore, porkers are obtained from early-maturing stocky breeds such as Berkshires and Middle Whites, and baconers from later-maturing breeds of leaner nature typified by the Large White and Tamworth. The desired end may also be achieved by cross-breeding, while several breeds are intermediate in type.

It must also be pointed out that pork and bacon pigs are killed long before they reach their maximum growth, for very fat mature animals of the larger breeds may attain 1,000 lb live-weight. As a guide to rationing it is useful to know the weights of pigs at different ages, and the figures given below are generally applicable except in the case of selected animals or those intensively fed—

TABLE 17 (5)—**Approximate live-weight in lb of commercial pigs**

Age in months	Pork type	Bacon type	Young breeding stock
0	3	3	3
1	14	14	14
2	32	32	32
3	55	50	42
4	85	80	67
5	120	115	97
6	—	155	130
7	—	200	165
8	—	245	200
9	—	—	230
12	—	—	280

It is obvious that pork and bacon pigs make similar increases in live-weight during the first 5 months, the former making rather larger gains in the fourth and fifth months. The feeding of both types may be considered together, for, on an average, the daily increase in live-weight amounts to about $\frac{3}{4}$ lb in the third, 1 lb in the fourth and rather more than 1 lb in the fifth month.

Reference to the data given in the section on food requirements shows that for pigs 3 months old the ratio between the total P.E. and S.E. of the ration should be 1 : 5, and at 5 months 1 : 6; further, that pigs weighing 50 lb (at about 3 months) require 2·5 lb of barley meal equivalent and 4·25 lb at 100 lb live-weight when fully fed ; for pork and bacon the amounts may be reduced by 10 and 20 per cent respectively. These figures may be taken as a guide to the amount of food fed, roughly 1 lb

[5]Watson, J. A. S., and More, J. A., 1945 " Agriculture. The science and practice of British Farming," p. 869 (Oliver and Boyd)

of meal per month of age for the pork pig, and rather less for the bacon pig. The pigs are fed indoors during the later stages of fattening, for warm dry conditions result in appreciable economy in meal.

The following mixtures meet the requirements of pigs in the early stages of fattening at the age of 3 to 4 months—

	S.E. (lb)	P.E. (lb)
40 lb barley meal	28·6	2·92
20 lb weatings	13·7	2·52
25 lb maize meal	19·4	1·90
10 lb white fish meal	5·9	5·30
5 lb bean meal	3·3	0·99
100 lb mixture	70·9	13·6

	S.E. (lb)	P.E. (lb)
50 lb barley meal	35·7	3·65
25 lb weatings	17·2	3·15
10 lb flaked maize	8·4	0·92
5 lb white fish meal	3·0	2·65
10 lb extracted soya-bean meal	6·4	3·83
100 lb mixture	70·7	14·2

Actually the protein-rich foods can be reduced in favour of the cereals in the fourth and fifth months, when a ratio of P.E. : S.E. of 1 to 5·5 or 6 suffices. A still wider ratio of 1 : 6 or 1 : 7 suffices during the last stages of fattening of porkers (5th month), and bacon pigs (6th–8th months), as provided, for example, in the following mixtures—

	S.E. (lb)	P.E. (lb)
50 lb barley meal	35·7	3·65
25 lb weatings	17·2	3·15
15 lb flaked maize	12·6	1·38
10 lb soya-bean meal (extracted)	6·4	3·83
100 lb mixture	71·9	12·0

	S.E. (lb)	P.E. (lb)
50 lb barley meal	35·7	3·65
15 lb oat meal	8·9	1·14
15 lb wheat meal	10·7	1·44
20 lb bean meal	13·2	3·94
100 lb mixture	68·5	10·2

For safety fish meal is omitted from these rations, although some feeders consider that no taint is produced when small quantities of high grade are

fed, and it could be included up to the last few weeks in any case. When omitted altogether, it may be replaced by meat and bone meal, or the ration supplemented with 2 per cent of the mineral mixture referred to at the beginning of the chapter. Many other foods might be used instead of the above cereals, and cooked potatoes replace barley meal at the rate of 3½ lb to 1 lb of meal and are excellent for fattening, while the value of milk products has already been emphasised. Pigs fed indoors should receive a small amount of green succulent food daily, or 2–5 per cent of the concentrates may be replaced by an equal weight of dried grass or lucerne meals.

It is also possible to reduce the amount of meal used for fattening purposes. This is accomplished under the Lehmann system of feeding used in Germany, and with considerable success in this country in modified forms during the period of national emergency. The young pigs are fed normally until they weigh about 50lb, when their meal (about 2½lb) is gradually replaced by an equal weight of meal made up of 70 per cent carbohydrate-rich and 30 per cent protein-rich concentrates, for example, 70 parts of a mixture of weatings and barley meal with 20 parts white fish meal and 10 parts extracted soya-bean meal. This basal ration is continued at the above rate, and the pigs are allowed to consume *ad lib.* any suitable cheap food available such as potatoes, roots, grass and forage crops, whey and swill. The young pig thus receives concentrated food rich in protein and minerals, and consumes increasing amounts of more bulky products as its capacity for food increases. Experiments at Cambridge have shown that equally good results can be obtained when the protein-rich food is maintained at the normal level of 10 per cent with great saving in expensive food.([6])

In addition to the feeding problems briefly discussed, it may be mentioned that pigs required for breeding purposes are fed less generously than either pork or bacon pigs, the aim being to enable them to make full healthy growth without fattening, that is during a sort of " store" period. This may be accomplished by feeding a less concentrated and more bulky ration, always remembering that the fibre content must be kept down to a safe level.

In conclusion, reference may also be made to the fact that, as in the case of other animals, the maintenance of an adequate plane of nutrition is but one aspect of successful husbandry, and the feeder must watch for the presence of any harmful effects. With reference to pig feeding, these

---

[6]WOODMAN, H. E., and EVANS, R. E., 1943, " The nutrition of the bacon pig. IX: The Lehmann method of pig feeding with particular reference to the balance of the basal meal and the use of cooked potatoes and molassed beet pulp as the supplemental foods," *J. agric. Sci.*, p. 155

include the development of anaemia which has already been mentioned, and the difficulties following weaning often due to intestinal worms which may be got rid of by suitable treatment as a routine practice at this stage. The reader should familiarise himself with the broader aspects of pig-breeding and management, for the systems of rearing are many and varied.

CHAPTER 21

THE FEEDING OF POULTRY

THE last quarter of a century has seen very marked developments in the methods of feeding and keeping poultry. As long as farmers were satisfied with low egg yields, the barn door fowl was kept and fed in a haphazard manner, but, with the demand for higher egg production, and the development of research into poultry nutrition and management, the older methods have, to a considerable extent, been abandoned in favour of more scientific husbandry.

General considerations

At the outset it is well to realise that the nutritional problems encountered differ in many respects from those already discussed in relation to other farm animals. This is due to the comparatively simple digestive system of the fowl, and the possession of several other physiological peculiarities. Fowls possess no teeth, and food passes without mastication from the mouth down the gullet into the crop, an organ which serves mainly for storage and moistening of food with the secretions from the mouth, gullet and crop. The latter opens into a small stomach or proventriculus where the food is mixed with gastric juice prior to entry into a muscular organ, the gizzard or ventriculus lined with a horny material. This organ serves to grind the food, a function which is greatly aided by the presence of grit consumed by the fowl. The crushed food now passes into the small intestine and is mixed with pancreatic juice and bile, whose functions have already been described in Chapter 6.

The grinding of food with the aid of grit is a feature peculiar to poultry and, although birds may be reared without grit, there is no doubt that it is essential for efficient digestion, and that birds denied it will immediately seek such material when allowed to do so. Insoluble grit surpasses limestone grit in efficiency, for the latter is too soft to withstand prolonged attrition in the gizzard, but is an excellent source of calcium.

When one considers the simplicity of the digestive system compared with that of other farm animals, it is not surprising that poultry make very little use of fibre. Some forms of fibre are digested to a very slight extent, but the chief function of this constituent is to improve the texture of food mixtures. In practice it is assigned no nutritive value as a food for poultry, and the amount is restricted to an extent consistent with the maintenance of palatability, usually about 5 per cent of the ration.

The question of palatability needs special consideration, for careful observation has shown that poultry lack any appreciable sense of smell or taste, but possess a well-developed sense of form and colour. Consequently, substances which might be rejected by most farm animals because of an unpleasant taste or smell, may not be unattractive to poultry, and grains with polished, shining surfaces, or brightly coloured foods, are eagerly consumed. Again, foods likely to cause discomfort are not readily eaten, and this applies to food presented on hard concrete or iron surfaces, which cause jarring of the beak. Grains with sharp edges, foods such as dried sugar beet pulp which swell excessively when moistened and cause discomfort in the crop, and dusty foods which tend to clog the mouth and respiratory passages, may be rejected by birds that have once suffered these discomforts. In selecting foods for poultry, therefore, attention should be given to all these points. The ration should be highly concentrated in nature, free from foods whose condition might cause discomfort, attractive in appearance, and should be offered with an abundant supply of grit and, of course, water. In addition, the provision of a sod of earth is beneficial to poultry fed indoors, for the soil is readily eaten and clears the bowel. It may also provide trace elements, which, together with other minerals and vitamins, are obtained in abundance by poultry on free range consuming a great variety of foods including insects, worms and slugs.

Another factor, which has already been discussed in Chapter 14, is the effect which a food may have on the quality of the product, in this case meat and eggs. While white meat is more popular than yellow meat, the public prefer eggs with richly coloured yolks. The colour of the body fat depends mainly on the breed, some giving white and others yellowish meat, but breeds which tend to give yellowish fat will yield meat of light colour if pigmented foods such as green foods, carrots and maize are withheld. Similarly the colour of the yolk, which depends mainly on the type of food, can be enriched by providing these foods, while wheat, oats, rice, barley and their by-products, fish and meat meals and milk produce pale yolks. Undesirable colours may be produced by some foods, namely, a greenish colour by linseed, and olive-green tints by the weeds penny-cress and shepherd's purse. The appearance of blood and meat spots, once thought to be produced by high-protein feeding, is probably due to the presence of ruptured blood vessels of the ovary and oviduct of hens prone to produce such eggs. As in the case of other animals, the consistency as well as the colour of the fat is influenced by the nature of the fat in the food, and foods containing a high proportion of unsaturated fatty acids, for example, the oil of linseed and hemp, produce a greasy carcass, whereas mutton fat and palm oil produce firm fat of light colour

despite the yellow colour of palm oil. Of the cereal foods, Sussex ground oats, barley and maize meals produce firm fat, the undesirable softening effect of the latter when fed to pigs being absent in the case of poultry; separated milk and potatoes are also very suitable for fattening.

Attention has been drawn to some physiological peculiarities of poultry compared with other farm stock and, in this connection, reference must be made to moulting, that is, the complete renewal of the feathered coating once a year, following four partial or complete moults in the first year. Feathers comprise about one quarter of the total protein of the body, and moulting may be considerably influenced by feeding. Generally, moulting commences when egg-laying ceases, although both may occur together, especially in the case of high producers. There are at least two ways in which the poultry keeper can influence the moult by due attention to feeding, for the loss of feathers and their replacement by a new set must take a considerable time and makes important nutritional demands. Feathers contain approximately 94 per cent of protein, and 2·6 per cent of sulphur mainly in the form of cystine, and less than 1 per cent of ash. Consequently, if moulting is to proceed rapidly, abundant protein and energy-giving foods must be supplied to provide for the growth of feathers in addition to bodily growth. Moreover, the protein supplied must be rich in cystine, provided by such foods as soya-bean meal, blood, meat or fish meals, and dried milk. These should be fed together with wheat, oats, maize and potatoes. By generous feeding the period of moulting may be reduced very appreciably, while under-feeding prolongs moulting and delays resumption of egg production.

Secondly, it is possible to induce moulting by rigidly reducing the quality—not the quantity—of the ration. Moulting generally occurs between September and January, a period when eggs are scarce. By stopping the supply of protein-rich foods, and feeding cereal products and potatoes, moulting may be induced in July and August, and completed in time for egg production during the period of normal scarcity. When moulting has set in, abundant protein-rich foods are given in order to accelerate the process.

Once egg-laying has begun, further nutritional demands have to be met. An average hen's egg weighs 2 oz and contains the following approximate percentages of nutrient substances: water 66, protein 12, fat 10. Further, the shell constitutes approximately one tenth of the weight and contains 5 grams of calcium carbonate. Particular attention must, therefore, be given to this constituent, especially as cereal grains and their products form a very high proportion of the foods used and are deficient in calcium, sodium and chlorine. For this reason such foods as dried milk and blood, meat and bone meals, and fish meals, comprise about 10 per

cent of the ration of poultry, and provide minerals and protein of high quality. Mineral supplements are also used to ensure an abundance for growth and egg production.

In supplementing the mineral ration for growing chicks, great care has to be taken not to provide excessive amounts of calcium or phosphorus which, associated with lack of manganese and chlorine, induce perosis or slipped tendon with swelling of the joints and bowing of the leg bones. On the other hand, deficiency of either of these constituents, or of vitamin D, upsets normal calcification and causes rickets. In practice large amounts of fish and bone meal, or steamed bone flour, are not included in the ration of chicks under 8 weeks old. Instead, the ration is supplemented with 1 to 2 per cent each of ground chalk or limestone and cod-liver oil.

For efficient egg production common salt is necessary in addition to calcium carbonate, and some authorities ascribe the advantages of animal proteins mainly to their content of the former constituent. In the absence of animal protein, it is advisable to include 0·5 per cent of common salt in the diet, and to allow free access to calcium carbonate in the form of ground limestone or oyster shell. Excess of common salt may prove fatal to poultry, although, as stated by Linton and Williamson, it is probable that this danger has been greatly exaggerated, for the minimum lethal dose for hens of about 4 lb weight is about 0·4 per cent of their live-weight, and greatly exceeds their normal requirements.([1])

In addition to the foregoing considerations relating to poultry foods, the question of bulk is as important as it is in the feeding of other farm animals, especially as poultry have neither the capacity for storing, nor the ability to digest any but small quantities of fibre. Whereas it is usual to assess the bulk of a ration in terms of dry matter (p. 122), a more direct measure is advocated in the case of poultry foods. One ounce of the mash is placed in a glass measuring cylinder and, after tapping with the fingers, the volume is read ; for maximum efficiency it should not exceed 70 cc. Figures giving the cubic capacity per ounce of several foods are given in *Bulletin No.* 7 of the Ministry of Agriculture and Fisheries (" The Scientific Principles of Poultry Feeding " by E. T. Halnan). They serve to indicate the bulkiness of individual foods, and of a mash made of similar foods such as meals, but cannot be added together when mealy and flaky foods are mixed, for meals settle between the flakes, and the mash occupies less space than the separate components. For this reason direct measurement only serves as an accurate estimate of the bulk of a mash.

Poultry are usually fed on a mixture of grain and mash—although an all mash system is sometimes preferred—the mash being so constituted

---

[1]Linton, R. G., and Williamson, G., 1943, " Animal nutrition and veterinary dietetics," p. 438 (Green and Son, Edinburgh)

as to make good the deficiency of whole cereals in protein and minerals. Grain is usually consumed with readiness, but large grains should be crushed to a suitable size, and oats and barley clipped and screened to remove awns and sharp points. Mash may be fed wet or dry, and opinion varies as to the better procedure. Dry mash feeding is labour-saving, but may lead to loss of food blown about by the wind. Mealy constituents may not be relished because they may cause respiratory troubles, and moistening is then an advantage. Enough water should be added to give the mash a crumbly consistency. Foods which absorb water and swell appreciably must be thoroughly moistened before feeding, and this is particularly important in the case of dried sugar beet pulp and biscuit meal. Chopped vegetables and potatoes may be incorporated in a wet mash made with cold or hot water, buttermilk or separated milk. Mash feeding has one great advantage ; it enables the ration to be adjusted at will to meet relatively low or high nutritional requirements by increasing or decreasing the proportion of bulky constituents. The consistency of a mash may be improved by the incorporation of an increased quantity of bran, and mixtures of food constituents are sometimes fed in pellet form to increase palatability, to reduce waste and for general convenience. At present, poultry foods are limited both in quantity and variety, and the best use has to be made of available grain products, greenstuff and household or other waste, some of which is sold as cooked " pudding." This aspect of the subject is dealt with by Halnan in " Emergency Poultry Feeding, Growmore Bulletin No. 5 of the Ministry of Agriculture and Fisheries."

Feeding standards

The fact that the starch and protein equivalent values of foods have been obtained as a result of feeding experiments with ruminant animals has already been emphasised, and it has been pointed out in this chapter that poultry are unable to digest fibre to any appreciable extent. It is evident, therefore, that the usual tables of nutritive value of foods can have little application to poultry. These facts, together with the lack of accurate information regarding nutritional requirements, have militated against the application of feeding standards to the rationing of poultry.

A great deal of progress in this direction has been made since the establishment of the National Poultry Institute at Cambridge, and as a result of the researches of Halnan, who, by feeding experiments with poultry, has determined the digestibility of a number of foods. The determination of protein digestibility was carried out by *in vitro* methods (p. 60), because the excretion of solid and liquid excrements together makes direct determination impossible. His results have enabled him to

state the nutritional requirements of poultry in terms of starch equivalents and digestible protein, and for a detailed account reference should be made to Bulletin 7 referred to above; an outline only of Halnan's recommendations will be given here.

In the absence of data giving the requirements of poultry for growth, analyses were carried out to determine the amounts of ash, protein and energy in the bodies of chicks at various ages, the amounts of food consumed being carefully determined. As a result of this work, it was concluded that " special attention should be given to the supply of protein and ash during the early stages of growth, and to the supply of energy and ash in the later stages", and that insufficient protein was generally given in the early stages, and insufficient ash in the later stages of growth. Bearing these facts in mind Halnan recommends the following mash and grain rations, the figures expressing the parts by weight of dry feed[2]—

	Chick mash to 8 weeks	Grower's mash 12 weeks onward	Layer's mash
Maize meal	33	35	$22\frac{1}{2}$
Linseed meal	3	3	—
Bran	14	15	15
Weatings or middlings ...	23	26	40
Sussex ground oats	5	10	10
Dried skim milk	7	—	—
Meat and bone or fish meal ...	7	7	$12\frac{1}{2}$
Dried yeast	3	$2\frac{1}{2}$	—
Limestone flour	$2\frac{1}{4}$	—	—
Salt	$\frac{5}{8}$	$\frac{1}{2}$	—
Ferric oxide	$\frac{1}{8}$	—	—
Cod-liver oil	2	1	—

Grain is introduced by sprinkling a little crushed wheat on the mash when the chicks are 4 weeks old, and kibbled maize is gradually introduced until at 15 weeks the adult grain mixture is being consumed. Layers receive 2 oz per head daily of a mixture of wheat and kibbled maize in the ratio of 3 : 2 by weight, and for growers the amount is varied according to the condition of the birds. Oyster shell or ground limestone should be available in a separate hopper from 7 weeks onwards and, when the chicks are on grass, the cod-liver oil may be omitted. A supply of grit must be provided, and a little is scattered over the mash in the early stages. As in the case of all farm stock, changes in food are made gradually, and a small quantity of the above grower's mash is mixed with the chick mash and the proportion gradually increased until grower's mash only is being fed.

[2]Halnan, E. T., 1946, " The scientific principles of poultry feeding," p. 43, Bulletin No. 7 of the Ministry of Agriculture and Fisheries (H.M. Sta. Office)

With regard to the amount of food consumed, there are no scientific data available stating the requirements of chicks in terms of protein and energy, and they are allowed to satisfy themselves with mixtures such as the above. The daily consumption of food by fowls of the same age varies widely because, under different systems of feeding and management, the birds will grow at different rates. Halnan found that an estimate of daily food consumption must be based on weight rather than age, and in Bulletin 7 he gives graphs for fowls and ducks relating the weekly consumption of food to the weight of the bird.

Requirements for egg production

Halnan found that protein-rich foods stimulate egg production, and that increased production was accompanied by higher food consumption ; also that light breeds give as good yields as heavy breeds, and are more economical for egg production, since they require less food for maintenance. The digestible protein required for maintenance per pound of body weight was found to be 0·625 g, and for producing a 2-oz egg, 12·5 g. On this basis Halnan's revised feeding standards for poultry are(3)—

Feeding standards for British breeds of poultry

1. Daily requirements (in grams) for maintenance—

Weight of bird in lb	*Digestible protein*	*Starch equivalent*
3	1·9	47·5
4	2·5	51·8
5	3·1	56·0
6	3·7	60·2

2. Requirements (in grams) for the production of a 2-oz egg—

Digestible protein	*Starch equivalent*
12·5	38·0

It is assumed that the foods provide sufficient calcium (the average 2-oz egg contains just over $\frac{1}{5}$-oz $CaCO_3$), or that limestone grit or oyster shell are available, 1 oz of either per 4 eggs laid.

Since poultry are fed in flocks, it is not possible to give as much attention to the yield and food requirements of individuals as it is in the case of dairy cows, and, for this reason, the reference made in Chapter 15

[3] Halnan, E. T., 1946, "The scientific principles of poultry feeding," p. 46, Bulletin No. 7 of the Ministry of Agriculture and Fisheries (H.M. Sta. Office)

to the effect that feeding standards are a guide to successful rationing rather than exact estimates of nutritional requirements, is of even greater significance in the present instance, when the best to be hoped for is the intelligent and economical use of feeding stuffs.

The grain and mash system of feeding usually adopted lends itself admirably to the use of the above standards, grain being fed in the morning and evening, wet mash mid-day, or dry mash from self-filling hoppers. Thus one procedure is to satisfy maintenance requirements with grain, and the production requirements with a mash designed for egg production. From the above table, a bird of a light breed weighing 4 lb requires 51·8 g S.E. for maintenance and, since 453·6 g=16 oz, this amounts to $51{\cdot}8 \times 16 \div 453{\cdot}6$ or 1·83 oz. Since one unit weight of wheat supplies 0·75 parts of S.E. (see table given below) 1·83 oz would be supplied by $1{\cdot}83 \div 0{\cdot}75 = 2{\cdot}4$ oz (approx.). Similarly 2·7 oz (approximately) of wheat would meet the maintenance S.E. required by heavy breeds weighing on an average $5\frac{1}{2}$ lb. When maintenance requirements are met in this way, more than enough protein is provided, the surplus contributing towards egg-production. The amount of grain usually fed is about 3 oz per day for light breeds, and $3\frac{1}{4}$ to $3\frac{1}{2}$ oz for heavy breeds, so that, in addition to supplying maintenance requirements, enough S.E. and protein are provided for 36 to 40 per cent daily egg production. It now remains to supply the energy and protein for additional eggs by means of a suitably balanced mash. The data in Table 18 are abstracted from Halnan's table, which, in addition to the starch equivalents (S.E.), digestible protein (D.P.), and bulkiness of poultry foods, gives the number of 2-oz eggs provided for in 1 lb of each food.([4])

This is best explained by means of an example. One unit, for example 1 lb of alfalfa meal, contains 0·108 and 0·226 parts of D.P. and S.E. respectively. One pound is equal to 453·6 grams, so that 1 lb of this meal contains $453{\cdot}6 \times 0{\cdot}108$ g D.P. and will provide the protein for $453{\cdot}6 \times 0{\cdot}108 \div 12{\cdot}5 = 3{\cdot}9$ two-oz eggs, 12·5 being the grams D.P. required to produce one 2-oz egg. In the same way 1 lb of the meal provides the S.E. for $453{\cdot}6 \times 0{\cdot}226 \div 38$ or 2·7 eggs, 38 g S.E. being the amount required per egg. When more than one food is considered, a mash balanced for egg production is obtained by selecting two or more foods in such quantities that the D.P. egg-numbers and S.E. egg-numbers add up to the same figure. The following examples based on Halnan's formula, suffice to illustrate the method adopted to calculate the amount of foods required to make a balanced mash, and the number of 2-oz eggs for which the mash provides.

[4]HALNAN, E. T., 1946, "The scientific principles of poultry feeding," pp. 59 and 60, Bulletin No. 7 of the Ministry of Agriculture and Fisheries (H.M. Sta. Office)

TABLE 18

Food	Proportion per unit of weight		Bulkiness (approx.) in c.c. per oz.	No. of 2-oz eggs provided for in 1 lb of meal	
	D.P.	S.E.	(Dry)	In D.P.	In S.E.
Alfalfa meal...	0·108	0·226	75	3·9	2·70
Barley and meal	0·076	0·651	43	2·8	7·77
Fish meal	0·474	0·543	43	17·2	6·48
Maize and meal	0·087	0·766	41	3·2	9·15
Meat meal	0·639	0·867	45	23·2	10·35
Meat and bone meal ...	0·464	0·661	45	16·9	7·89
Milk (dried skim)	0·314	0·764	48	11·4	9·12
Oats	0·092	0·589	53	3·3	7·03
Potatoes	0·016	0·181	—	0·6	2·16
Soya-bean meal (extd.) ...	0·419	0·678	52	15·2	8·09
Wheat (strong varieties) ...	0·166	0·752	39	4·2	8·98
Wheat (weak varieties) ...	0·083	0·749	40	3·0	8·94
Wheat bran	0·128	0·371	100-130	4·6	4·43
Wheat middlings (fine) ...	0·072	0·755	52	2·6	9·01
Wheat middlings (coarse) ...	0·142	0·571	65-70	5·2	6·82

1. *Balancing a mash using two foods.* How many pounds of weatings (coarse middlings) should be added to 1 lb of meat and bone meal to give a balanced mash, these being a protein-rich and a carbohydrate-rich food respectively?

Since the D.P. egg-numbers of the mixture will equal the S.E. egg-numbers the procedure is as follows—

Let x=lb of coarse middlings required.

Then $1\times$D.P. egg-number for meat and bone meal+($x\times$D.P.) egg-number for coarse middlings=$1\times$S.E. egg-number for meat and bone meal+($x\times$S.E.) egg-number for coarse middlings.

Selecting the appropriate figures from the table given above—

$$1\times16{\cdot}9+5{\cdot}2x=1\times7{\cdot}89+6{\cdot}82x$$
$$\text{i.e., } 16{\cdot}9-7{\cdot}89=(6{\cdot}82-5{\cdot}2)x$$
$$\text{whence } 9{\cdot}01=1{\cdot}62x$$
$$\text{and } \quad x=5{\cdot}6 \text{ (approx.)}$$

Thus 1 lb of meat and bone meal mixed with 5·6 lb of Sussex ground oats, or 10 and 56 lb respectively, provide a balanced mash. Now since

1 lb of these foods provides D.P. for 16·9 and 5·2 eggs respectively, 66 lb provide for $(10\times 16{\cdot}9)+(56\times 5{\cdot}2)$ eggs$=169+291{\cdot}2=460{\cdot}2$ eggs, and 1 lb of the mash provides for $460{\cdot}2\div 66=7{\cdot}0$ two-ounce eggs.

In practice, more than two foods are used in making a mash, and the procedure adopted in such a case will now be considered.

2. *Balancing more than two foods for egg production.* In this case the D.P. egg-number and S.E. egg-number of the mixture of energy-producing foods is first worked out, and the resultant mash equated against the protein-rich food as in the above example, e.g. a mash containing 3 parts of coarse middlings, 2 parts bran, and 1 part each of Sussex ground oats and maize meal to be used with fish meal—

	D.P. eggs	S.E. eggs
3 coarse middlings	15·6	20·46
2 bran	9·2	8·86
1 Sussex ground oats	3·3	7·03
1 maize meal	3·2	9·15
7 lb of mixed meal contains	31·3	45·50
1 lb of mixed meal contains	4·47	6·50
and 1 lb of fish meal	17·2	6·48

Following the method used in the previous example—

$$17{\cdot}2 - 4{\cdot}47x=6{\cdot}48 - 6{\cdot}50x$$
$$\text{whence } 2{\cdot}03x=10{\cdot}72$$
$$\text{and } x=5{\cdot}3$$

so that 5·3 lb of the mixture would be mixed with 1 lb of fish meal. Using the appropriate D.P. egg-numbers, (4·47 for the mixed cereals and 17·2 for the fish meal), 6·3 lb of the mash provide for $(5{\cdot}3\times 4{\cdot}47)+(1\times 17{\cdot}2)=23{\cdot}7+17{\cdot}2=40{\cdot}9$ two-ounce eggs, and 1 lb provides for 6·5 eggs.

It remains to calculate the amount of such a mash necessary to supplement a given amount of grain for an estimated egg production, for example 80 per cent. If one supposes that 3 oz of grain per head per day suffices for maintenance and say 39 per cent egg production, then 80 — 39 or 41 eggs have to be provided for by the mash. Since 1 lb provides for 6·5 eggs, 41 eggs will be provided for by $41\div 6{\cdot}5=6{\cdot}3$ or approximately $6\frac{1}{4}$ lb of mash. Thus a flock of 100 light breed pullets producing 80 eggs would require 300 oz or $18\frac{3}{4}$ lb of grain, and $6\frac{1}{4}$ lb mash per day. Similarly, since 3·4 oz of grain suffice to maintain a $5\frac{1}{2}$ lb bird and provide for 36 per cent egg production, a flock of 100 heavy breed pullets would require 340 oz or $21\frac{1}{4}$ lb grain, and $44\div 6{\cdot}5=6{\cdot}77$ or approximately $6\frac{3}{4}$ lb of mash.

An estimated daily egg production of 80 eggs per 100 birds is a very high one; in practice it will vary a good deal. The best birds may produce 200 or more eggs in a season, a majority may be expected to produce 150–180, whereas a few will give only about 120 or even fewer eggs. The level of production will be highest in the spring, and will decrease when the time of moulting approaches and laying generally ceases. The feeding of a flock of poultry in such a way as to make the best use of available food and stimulate maximum production, calls for considerable skill on the part of the poultry man.

From the foregoing discussion, it will be seen that the general principles underlying poultry nutrition are now fairly well established, while advances have been made in determining their quantitative requirements. These will vary considerably with the system adopted, and, although layers' mashes should generally contain some 12–15 per cent of protein, birds confined indoors or in batteries require more protein, whereas mashes with a lower protein content suffice for poultry having daily access to fresh grass.

For this reason and those already mentioned, the application of feeding standards has not been practised to an appreciable extent, and the rations given by various authorities have been drawn up from the results of practical experience, more attention being given to such qualitative aspects as bulk, freshness and palatability, than to strict quantitative requirements.

Brief reference will now be made to one other aspect of poultry husbandry, namely, the production of table poultry.

Fattening.—For this purpose chicks are reared on grass runs until about 3–4 months old, or cockerels of dual purpose breeds are used. Although fattening may be effected with the birds on grass, whiter flesh is obtained by the more usual method of crate feeding when the birds receive carbohydrate-rich foods for about a fortnight. Sussex ground oats made into a gruel with skim milk is a popular food, but mashes containing about equal weights of Sussex ground oats, weatings, barley and/or maize meals, with 5–10 per cent of dried skim milk may be used. Fattening may be taken a stage further by cramming for a period of a week or so with a mixture such as that recommended by Halnan, namely, 13 parts Sussex ground oats : 1 dried skim milk : 1 rendered mutton fat : 20 water. After it has fermented for 12 to 24 hours, the mixture of even creamy consistency is forced into the crop by means of a special cramming machine. The process is repeated a second time each day when the crop is practically empty. The fattened birds weigh $3\frac{1}{2}$ to 4 lb or more. There is, in addition, a small demand for cockerels of light breeds fattened to give " petit poussin " weighing about 1 lb or less.

In this chapter most attention has been given to the more general principles of poultry feeding, and no attempt has been made to give detailed rations for poultry, because the systems of management are so varied, and influence the nutritional requirements to such an extent, that feeding and management have to be considered together. The obvious difference in the requirements of poultry on free range, with access to a great variety of natural foods, fresh air, sunshine and exercise, and those kept in batteries, serves to emphasise this point. There are many systems of management more or less intensive, and the reader will find details of these, together with appropriate rations for fowls, ducks, geese and turkeys in standard works on animal husbandry. As in the case of all farm livestock, careful attention to such details as regular feeding, including a supply of clean water, adequate housing and constant watch for disease, is of primary importance.

SELECTED BIBLIOGRAPHY
OF BOOKS AND BULLETINS FOR FURTHER READING

CHAPTERS 1-7

READ, John. An Introduction to Organic Chemistry (G. Bell and Sons, Ltd.).
BOGERT, L. J. Fundamentals of Chemistry (W. B. Saunders Company).
READ, John. A Text-book of Organic Chemistry (G. Bell and Sons Ltd.).
KARRER, Paul. Organic Chemistry. Translated by A. J. Mee (Elsevier Publishing Co.).
TYLER, C. Organic Chemistry for Students of Agriculture (George Allen and Unwin Ltd.).
PARSONS, T. R. Fundamentals of Biochemistry in Relation to Human Physiology (W. Heffer and Sons Ltd.).
FEARON, W. R. Introduction to Biochemistry (William Heinemann Medical Books, Ltd.).
HARROW, B. Text-book of Biochemistry (W. B. Saunders Co.).
BALDWIN, Ernest. Dynamic Aspects of Biochemistry (Cambridge University Press).
GORTNER, R. A. Outlines of Biochemistry (John Wiley and Sons).
BODANSKY, M. Introduction to Physiological Chemistry (John Wiley and Sons).
MARSHALL, F. H. A., and HALNAN, E. T. Physiology of Farm Animals (Cambridge University Press).
SHERMAN, H. C. Chemistry of Food and Nutrition (The Macmillan Co.).
HARRIS, L. J. Vitamins in Theory and Practice (Cambridge University Press).
ROSENBERG, H. R. Chemistry and Physiology of the Vitamins (Interscience Pub. Inc., N.Y.).
MCCULLUM, E. V., ORENT-KIELES, E., and DAY, H. G. The Newer Knowledge of Nutrition (The Macmillan Co.).
MAYNARD, L. A. Animal Nutrition (McGraw Hill Book Co.).
LINTON, R. G., and WILLIAMSON, G. Animal Nutrition and Veterinary Dietetics (Green and Sons).
MORRISON, F. B. Feeds and Feeding (The Morrison Publishing Company).
STILES, W. Trace Elements in Plants and Animals (Cambridge University Press).
MONIER-WILLIAMS, G. W. Trace Elements in Food (Chapman and Hall, Ltd.).

CHAPTERS 8-11

SANDERS, H. G. An Outline of British Crop Husbandry (Cambridge University Press).
... Farm Crops. Vols. I-IV. By many specialists. Edited by W. R. G. Paterson (The Gresham Publishing Co., Ltd.).
BELL, D. H. Cultivated Plants of the Farm (Cambridge University Press).
RATHER, H. C. Field Crops (McGraw Hill Book Co.).
... Advances in Grassland Husbandry and Fodder Production. Bull. 32. 1945. Commonwealth Bureau of Pastures and Forage Crops, Aberystwyth.
RUSSELL, F. C. Minerals in Pastures. Deficiencies and Excesses in Relation to Animal Health. Technical Communication, No. 15, 1944. Commonwealth Bureau of Animal Nutrition, Rowett Research Institute, Aberdeen.
STAPLEDON, R. G., and HANLEY, J. A. Grass Land. Its Management and Improvement (Oxford, Clarendon Press).
WATSON, S. J. The Science and Practice of Conservation : Grass and Forage Crops. Vols. 1 and 2. (The Fertiliser and Feeding Stuffs Journal.)

WATSON, S. J. Silage and Crop Preservation (Macmillan and Co.).

ROBERTS, E. J. Grass Drying. A.R.C. Report Series No. 2. 1937 (H.M. Stationery Office).

ROBERTS, E. J. Fodder Conservation with Special Reference to Grass Drying. A.R.C. Report Series No. 5. 1939 (H.M. Stationery Office).

BURTON, W. G. The Potato (Chapman and Hall, Ltd.).

... Notes on Animal Feeding Stuffs. Animal Husbandry Department, Royal Veterinary College.

KENT-JONES, D. W., and AMOS, A. J. Modern Cereal Chemistry (The Northern Publishing Company).

LINTON, R. G., and WILLIAMSON, G. Animal Nutrition and Veterinary Dietetics (Green and Sons).

MORRISON, F. B. Feeds and Feeding. (The Morrison Publishing Company).

HALNAN, E. T., and GARNER, F. H. The Principles and Practice of Feeding Farm Animals (Longmans, Green and Co.).

ELLIS, J. B. Feeding of Farm Livestock (Crosby, Lockwood and Son Ltd.).

Ministry of Agriculture and Fisheries (H.M. Stationery Office)—

WOODMAN, H. E. Home grown Foodstuffs. Bulletin No. 13.

WOODMAN, H. E. Oil Cakes and Extracted Meals. Bulletin No. 11.

WOODMAN, H. E. Ensilage. Bulletin No. 37.

CHAPTERS 12-21

WATSON, J. A. S., and MORE, J. A. Agriculture: The Science and Practice of British Farming (Oliver and Boyd).

FREAM, W. Elements of Agriculture (John Murray.)

HAMMOND, John. Farm Animals. Their Breeding, Growth and Inheritance (Edward Arnold and Co.).

KELLNER, O. The Scientific Feeding of Animals. Translated by W. Goodwin (Duckworth).

WOOD, T. B. Animal Nutrition (University Tutorial Press).

LINTON, R. G., and WILLIAMSON, G. Animal Nutrition and Veterinary Dietetics (Green and Sons).

MAYNARD, L. A. Animal Nutrition (McGraw Hill Book Co.).

ARMSBY, H. P. The Nutrition of Farm Animals (The Macmillan Co.).

HALNAN, E. T., and GARNER, F. H. The Principles and Practice of Feeding Farm Animals (Longmans, Green and Co.).

ELLIS, J. B. Feeding of Farm Livestock (Crosby, Lockwood and Son, Ltd.).

GARNER, F. H. The Cattle of Britain (Longmans, Green and Co.).

GARNER, F. H. British Dairying (Longmans, Green and Co.).

THOMAS, J. F. H., with Chapters by MOSES GRIFFITH, MARTIN JONES and A. R. WANNOP. Sheep (Faber and Faber Ltd.).

FRASER, A. Sheep Production (Thomas Nelson and Sons, Ltd.).

FRASER, A. Sheep Farming (Crosby, Lockwood and Son, Ltd.).

FISHWICK, V. C. Pigs. Their Breeding, Feeding and Management (Crosby, Lockwood and Son, Ltd.).

JULL, M. A. Poultry Husbandry (McGraw Hill Book Company).

ROBINSON, Leonard. Modern Poultry Husbandry (Crosby, Lockwood and Son Ltd.).

Ministry of Agriculture and Fisheries (H.M. Stationery Office):—

WOODMAN, H. E. Rations for Livestock. Bulletin No. 48.

MACKINTOSH, J. The Feeding of Dairy Cows. Bulletin No. 42.

STEWART, W. A. Pig-keeping. Bulletin No. 32.

HALNAN, E. T. The Scientific Principles of Poultry Feeding. Bulletin No. 7.

APPENDIX

The data in Tables 1 and 2, are taken from Bulletin No. 48, of the Ministry of Agriculture and Fisheries and reproduced here by permission of the Controller, H.M. Stationery Office.

TABLE 1.—Composition and nutritive value of feeding stuffs

	Average composition per cent as shown by chemical analysis						*Digestible nutrients per cent*					*Calculated from digestible nutrients*		
				Carbo-hydrates						Carbo-hydrates				Per 100 lb
	Dry matter	Crude protein	Oil (ether extract)	Nitrogen-free extractives	Crude fibre	Ash	Crude protein	True protein	Oil (ether extract)	Nitrogen-free extractives	Fibre	Nutritive ratio approx.	V	Starch Equivalent
Roots												1 :		
Carrots	13·0	1·2	0·2	9·3	1·4	0·9	0·8	0·4	0·1	8·9	0·7	12	87	8·8
Kohl rabi	12·7	2·0	0·1	8·2	1·4	1·0	0·7	0·3	—	7·4	0·6	11	90	8·3
Mangolds, intermediate...	12·0	1·0	0·1	9·4	0·7	0·8	0·7	0·1	—	8·5	0·3	13	70	6·2
Potatoes	23·8	2·1	0·1	19·7	0·9	1·0	1·1	0·6	—	17·7	—	16	100	18·5
Sugar-beet	23·4	1·1	0·1	20·4	1·1	0·7	0·8	0·3	—	19·3	0·4	25	75	15·0
Swede turnip	11·5	1·3	0·2	8·1	1·2	0·7	1·1	0·3	—	7·5	0·8	7	85	7·3
Turnip	8·5	1·0	0·2	5·7	0·9	0·7	0·6	0·2	—	5·2	0·3	9	77	4·4
Green foods														
Cabbage, drumhead	11·0	1·5	0·4	5·9	2·0	1·2	1·1	0·7	0·2	4·6	1·4	6	94	6·6
,, open-leaved	15·3	2·5	0·7	8·1	2·4	1·6	1·8	1·2	0·4	6·5	1·7	5	94	9·5
Kale, thousand-headed	15·8	2·2	0·4	8·4	3·1	1·7	1·7	1·2	0·17	7·5	1·8	5·7	92	10·3
,, marrow-stem (unthinned) ...	14·0	2·2	0·5	6·9	2·5	1·9	1·7	1·1	0·3	6·1	1·6	4·9	93	9·1
,, marrow-stem (singled-out) ...	13·9	2·1	0·3	7·2	2·5	1·8	1·6	1·0	0·18	6·4	1·5	5·2	93	9·0
Mustard	14·9	2·9	0·4	7·3	2·9	1·4	1·9	1·3	0·2	4·9	1·5	4	90	7·2
Rape	14·1	2·8	0·8	5·7	3·5	1·3	2·0	1·3	0·5	3·9	1·9	3	87	6·9
Sugar-beet tops	16·2	2·0	0·5	8·7	1·6	3·4	1·4	0·9	0·3	7·2	1·1	6	84	8·6
Barley in flower	31·4	2·2	0·5	16·8	9·9	2·0	1·5	1·3	0·3	12·1	6·4	12	79	16·1
Oats in flower	23·2	1·9	0·6	10·4	8·5	1·8	1·4	1·2	0·4	6·5	4·9	9	75	10·0
Rye	23·4	3·0	0·9	10·3	7·5	1·7	2·1	1·4	0·5	7·0	4·9	6	80	11·3
Grasses														
Pasture grass, close grazing :														
Non-rotational	20·0	5·3	1·1	8·9	2·6	2·1	4·5	3·8	0·7	7·8	2·1	2·5	95	14·7

Rotational, with 3-w'kly intervals* ...	20·0	4·5	1·3	9·3	3·1	1·8	3·7	3·2	0·8	8·0	2·5	3·3	94	14·6
Rotational, with monthly intervals*...	20·0	3·5	1·0	9·2	4·5	1·8	2·6	2·3	0·5	7·6	3·7	4·8	91	13·4
Pasture grass, extensive grazing :														
Spring value, running off during summer	20·0	3·5	0·8	9·7	4·0	2·0	2·5	1·7	0·4	7·3	2·6	4	91	11·2
Winter pasturage (after close-grazing, allowing free growth from end of July to December)	20·0	3·1	0·6	10·3	4·4	1·6	2·0	1·5	0·15	7·9	2·6	5·5	90	11·4
Ryegrass, perennial	24·8	2·9	0·7	11·5	7·1	2·6	1·8	1·3	0·3	7·4	4·0	7	81	10·6
,, Italian	25·0	3·4	1·0	11·6	6·2	2·8	2·1	1·3	0·5	7·7	3·6	6	85	11·4
Timothy	33·1	3·1	1·0	17·6	9·2	2·2	1·6	1·0	0·5	11·1	4·8	11	79	14·0
Green legumes														
Alsike	15·0	3·3	0·6	5·1	4·5	1·5	2·1	1·5	0·4	3·6	2·2	3	79	6·3
Crimson clover	18·5	2·8	0·7	6·9	6·2	1·9	2·1	1·5	0·5	5·2	3·5	5	81	8·9
Red clover, beginning to flower ...	19·0	3·4	0·7	8·1	5·2	1·6	2·5	1·7	0·5	6·3	3·0	4	86	10·2
White clover, beginning to flower ...	18·5	4·4	0·8	6·9	4·3	2·1	2·8	1·9	0·5	4·7	2·6	3	88	8·8
Beans, beginning to flower	15·0	3·2	0·8	5·7	3·3	2·0	2·3	1·5	0·5	4·1	1·6	3	88	7·1
Lucerne (in early flower)	24·0	4·1	0·4	9·9	7·2	2·4	3·1	2·0	0·1	6·6	3·2	3·2	80	10·3
,, (in bud)	22·0	4·5	0·5	9·0	6·2	1·8	3·6	2·4	0·1	6·8	3·1	2·8	84	11·3
,, (before bud)	15·0	3·8	0·4	5·7	3·3	1·8	3·2	2·1	0·13	4·6	2·1	2·2	91	9·0
Peas, beginning to flower	16·8	3·5	0·6	5·6	5·9	1·2	2·4	1·6	0·3	3·7	3·0	3	77	6·8
Sainfoin, in flower	20·0	3·5	0·6	7·8	6·9	1·2	2·3	1·6	0·3	4·8	3·2	4	76	7·6
Tares, in flower	17·5	3·2	0·5	7·2	5·1	1·5	2·2	1·4	0·3	4·9	2·3	4	83	7·5
Silage														
Clover, red	21·7	4·4	1·2	7·1	6·5	2·5	2·9	1·7	0·6	5·1	3·5	3	81	9·2
Grass (first quality)	21·0	3·8	1·0	9·8	4·3	2·1	2·7	1·0	0·6	7·3	3·1	4·3	91	12·8
,, (second quality)	24·5	3·5	0·9	11·3	6·6	2·2	2·4	0·9	0·5	7·4	4·4	5·4	84	12·6
,, (hay maturity)	25·0	2·6	1·0	10·5	8·4	2·5	1·8	1·0	0·5	6·1	4·9	7	75	10·2
Marrow-stem kale	15·9	2·0	0·5	7·2	3·7	2·5	1·5	1·0	—	6·1	2·8	6	89	9·2
Oats, green	23·7	1·9	0·8	10·7	8·5	1·8	1·1	0·6	0·4	5·9	5·1	11	72	8·9
Sugar-beet tops	23·0	2·4	0·7	9·1	3·4	7·4	1·5	0·2	0·3	7·2	2·5	7	91	9·5
Vetch and oats, green fruity	27·3	3·4	1·2	12·5	8·0	2·2	2·2	1·1	0·9	8·7	4·6	7	76	12·8
,, ,, ,, acid brown	34·6	5·6	1·5	12·9	11·4	3·2	3·8	1·9	1·2	6·4	5·5	4	76	13·0
Hay														
Clover, red, good	83·5	13·5	2·9	37·1	24·0	6·0	8·5	5·5	1·7	26·0	11·3	5	84	38
Lucerne, before flowering	84·0	16·2	2·4	31·1	27·0	7·3	12·1	8·1	1·1	21·1	11·3	3	76	32
,, in full flower	83·5	14·2	2·6	29·2	29·5	8·0	9·7	6·2	1·2	18·1	13·2	4	68	27

*Data for fore-flush period should be taken as for non-rotational close-grazing

TABLE 1 (continued)

	Average composition per cent as shown by chemical analysis						Digestible nutrients per cent					Calculated from digestible nutrients		
				Carbo-hydrates						Carbo-hydrates				Per 100 lb
	Dry matter	Crude protein	Oil (ether extract)	Nitrogen-free extractives	Crude fibre	Ash	Crude protein	True protein	Oil (ether extract)	Nitrogen-free extractives	Fibre	Nutritive ratio approx.	V	Starch Equivalent
Hay—contd.														
Lucerne, in half flower (very good quality) ...	84·0	18·9	1·1	30·6	25·4	8·0	13·9	9·8	—	20·4	12·2	1 : 2·4	81	37
Meadow hay, poor	85·7	7·5	1·5	38·2	33·5	5·0	3·4	2·5	0·5	19·3	15·6	11	59	22
,, ,, good	85·7	9·7	2·5	41·0	26·3	6·2	5·4	3·8	1·0	25·7	15·0	8	80	37
,, ,, very good	84·0	13·5	3·0	40·5	19·3	7·7	9·2	6·5	1·5	30·1	12·7	5	93	48
,, ,, aftermath, good	85·2	11·5	3·4	39·3	22·5	8·5	6·9	5·6	1·6	26·1	14·0	6	88	43
Oats (milk stage)	86·0	8·1	2·6	40·7	27·8	6·8	4·4	—	1·6	22·9	14·5	9	76	34·0
Seeds hay (ryegrass and clover) ...	86·0	12·0	2·8	37·4	27·5	6·3	6·2	3·6	1·2	22·0	13·2	6	73	30
Straws														
Barley straw, spring	86·0	3·3	1·8	42·4	33·9	4·6	0·8	0·6	0·6	22·5	18·3	52	54	23
Bean straw (including pods)	86·0	4·5	0·8	33·0	43·1	4·6	2·2	1·3	0·5	22·0	18·7	19	43	19
Clover straw (red)	84·0	9·1	1·8	22·8	44·6	5·7	4·0	3·1	0·6	11·1	16·4	7	22	7
Oat straw, spring	86·0	2·9	1·9	42·4	33·9	4·9	1·0	0·8	0·6	19·4	18·3	39	50	20
,, chaff (glumes), spring	86·0	6·0	2·1	44·8	22·8	10·3	2·2	1·7	1·0	21·9	10·2	16	81	29
Oat straw winter	86·0	1·9	1·5	43·1	34·6	4·9	0·6	0·4	0·5	19·8	19·7	67	51	21
,, straw chaff ,, ...	85·0	3·8	2·3	40·7	32·6	5·6								
Pea, haulm	86·0	9·2	1·6	36·0	33·4	5·8								
Wheat straw, spring	86·0	2·9	1·3	39·8	35·9	6·1	0·1	—	0·4	14·7	18·0	336	39	13
,, straw, winter	86·0	2·1	1·3	40·7	36·6	5·3	0·1	—	0·4	15·0	18·3	342	38	13
Grains and Seeds														
CEREALS														
Barley	85·1	10·0	1·5	66·5	4·5	2·6	7·6	7·0	1·2	60·9	2·5	9	98	71·4

Maize	87·0	9·9	4·4	69·2	2·2	1·3	7·9	7·4	2·7	63·7	0·8	9	100	77·6
Oats	86·7	10·3	4·8	58·2	10·3	3·1	8·0	7·2	4·0	44·8	2·6	7	95	59·5
Rye	86·6	11·5	1·7	69·5	1·9	2·0	9·6	8·7	1·1	63·9	1·0	7	95	71·6
Wheat	86·6	12·1	1·9	69·0	1·9	1·7	10·2	9·0	1·2	63·5	0·9	7	95	71·6
LEGUMES														
Beans	85·7	25·4	1·5	48·5	7·1	3·2	20·1	19·3	1·2	44·1	4·1	2	96	65·8
Peas	86·0	22·5	1·6	53·7	5·4	2·8	19·4	16·9	1·0	49·9	2·5	3	98	69·0
OIL SEEDS														
Coconut	85·0	5·5	59·0	15·0	4·0	1·5								
Cotton seed, Egyptian	91·2	19·6	23·9	21·5	21·2	5·0	13·4	12·0	20·7	10·7	16·1	6	94	80·6
Groundnuts, earth or pea-nuts	94·0	26·8	44·9	17·5	2·6	2·2	24·1	22·2	40·3	14·7	0·2	4	99	131·4
Linseed	92·9	24·2	36·5	22·9	5·5	3·8	19·4	18·1	34·7	18·3	1·8	5	99	119·2
Palm nut kernels	91·6	8·4	48·8	26·8	5·8	1·8	8·0	7·8	46·5	22·5	3·5	16	99	143·6
Soya-bean	90·0	33·2	17·5	30·5	4·1	4·7	29·5	26·2	15·8	20·8	1·7	2	98	78·9
Oil Cakes and Meals														
Coconut cake	88·6	21·2	8·0	42·4	11·5	5·5	16·6	16·2	7·8	35·1	7·3	4	100	76·8
,, ,, meal	88·7	19·5	6·7	42·5	13·6	6·4	15·3	14·9	6·5	35·4	8·6	4	100	73·6
Cotton cake, Bombay	87·7	20·2	4·8	35·2	21·7	5·8	15·6	14·8	4·5	18·9	4·4	2	84	40·0
,, ,, Brazilian	89·0	27·1	5·4	27·1	24·9	4·5	20·8	19·7	5·0	14·7	5·2	2	84	42·0
,, ,, Egyptian	87·9	23·2	5·0	32·6	21·3	5·8	17·8	16·8	4·6	17·7	4·5	2	84	41·6
,, ,, decorticated	90·2	41·2	8·0	26·5	7·8	6·7	35·4	33·9	7·5	17·7	2·2	1	97	68·4
Cotton seed meal	91·3	43·6	8·0	25·8	7·7	6·2	37·6	36·0	7·6	17·4	2·1	1	97	70·1
Groundnut cake, decorticated	89·7	46·8	7·5	23·2	6·4	5·8	42·0	40·6	6·8	19·7	0·5	1	98	73·0
,, ,, ,, undecorticated	89·7	30·2	9·1	21·8	22·9	5·7	27·7	26·8	8·2	18·4	2·6	1	86	56·8
Groundnut meal, undecorticated extracted	92·4	31·8	1·9	29·1	25·3	4·3	29·2	28·3	1·5	20·0	2·9	1	84	44·4
Linseed cake, English made	88·8	29·5	9·5	35·5	9·1	5·2	25·3	23·9	8·7	28·5	4·5	2	97	74·0
,, ,, foreign	89·0	32·3	9·9	32·2	8·7	5·9	27·8	26·3	9·1	25·8	4·3	2	97	74·5
Linseed meal, extracted	88·2	35·7	3·1	33·9	9·0	6·5	30·8	30·0	2·8	27·2	4·5	1	96	63·7
Maize germ meal	89·2	13·0	12·5	56·0	4·1	3·6	10·4	10·2	11·5	47·0	2·5	7	97	84·3
,, flaked	89·0	9·8	4·3	72·5	1·5	0·9	9·4	9·0	2·0	70·4	0·5	8	100	84·0
Palm kernel cake, English made	89·0	19·2	6·0	46·5	13·4	3·9	17·5	16·4	5·3	39·4	5·1	3	100	73·2
,, ,, meal, extracted	90·0	19·0	2·0	49·0	16·0	4·0	17·1	16·0	1·9	43·5	8·0	3	100	71·3
Soya-bean cake	85·5	43·1	5·6	26·3	5·1	5·4	38·8	35·0	5·1	20·4	3·7	1	97	68·9
,, ,, meal, extracted	88·7	44·7	1·5	31·9	5·1	5·5	40·3	36·3	1·4	24·7	3·6	1	97	64·0

TABLE 1 (continued)

	Average composition per cent as shown by chemical analysis						*Digestible nutrients per cent*					*Calculated from digestible nutrients*		
	Dry matter	Crude protein	Oil (ether extract)	Carbo-hydrates: Nitrogen-free extractives	Carbo-hydrates: Crude fibre	Ash	Crude protein	True protein	Oil (ether extract)	Carbo-hydrates: Nitrogen-free extractives	Carbo-hydrates: Fibre	Nutritive ratio approx.	V	Per 100 lb Starch Equivalent
By-products														
Barley brewers' grains, fresh ...	32·4	7·5	2·8	14·6	6·1	1·4	5·5	5·2	2·4	9·1	2·4	1 : 3	86	18·4
,, ,, ,, dried	89·7	18·3	6·4	45·9	15·2	3·9	13·0	12·1	5·6	27·6	7·3	4	84	48·3
,, distillers' ,, fresh	26·2	8·4	3·0	10·4	3·6	0·8	6·2	5·8	2·6	6·4	1·7	2	86	16·2
,, ,, ,, dried	92·0	27·7	11·6	40·8	10·1	1·8	19·6	18·7	10·2	25·3	4·8	3	84	57·2
,, malt coombs	90·0	24·4	2·0	42·4	14·0	7·2	19·9	12·0	1·5	30·9	12·7	3	75	43·4
Blood meal	86·0	81·0	0·8	1·5	—	2·7	72·7	63·6	0·8	—	—	—	100	62·9
Fish meal, white	87·0	61·0	3·5	1·5	—	21·0	55·0	51·0	3·3	1·2	—	—	100	58·9
Grass, dried (frequently cut)	90·0	20·3	5·8	41·9	14·0	8·0	16·7	14·4	3·6	36·0	11·3	3·3	94	65·7
,, ,, (cut less frequently) ...	90·0	15·8	4·5	41·4	20·3	8·0	11·7	10·4	2·3	34·2	16·7	4·8	91	60·3
Lucerne meal, English (from crop just coming into flower bud) ...	91·0	22·3	2·9	36·4	18·0	11·4	15·9	11·2	1·3	28·4	9·5	2·5	91	50·1
Lucerne meal, English (from crop in early flower)	91·0	16·2	2·4	37·7	24·5	10·2	11·6	9·3	0·7	27·8	11·2	3·5	86	44·1
Lucerne leaf meal, American ...	91·0	21·4	1·9	40·6	16·0	11·1	16·3	14·7	—	31·5	7·9	2·4	92	50·2
Maize gluten feed	89·6	23·5	3·4	56·7	3·5	2·5	20·0	18·4	2·7	49·3	2·5	3	100	75·6
,, ,, meal	90·9	35·5	4·7	47·5	2·1	1·1	30·6	30·3	4·4	42·6	—	2	100	81·5
Meat and bone meal*	90·3	50·3	15·0	1·0	—	24·0	39·2	29·2	14·3	—	—	1	100	67·8
Pure meat meal	89·2	72·2	13·2	—	—	3·8	67·2	63·6	12·5	—	—	—	100	91·0
Feeding meat meal (low fat)	93·0	66·7	2·9	4·0	—	19·4	58·6	43·4	2·4	3·9	—	—	100	59·6
Milk, buttermilk...	9·2	3·6	0·8	4·1	—	0·7	3·4	3·4	0·8	4·1	—	2	100	9·2
,, cow's, whole	12·8	3·4	3·9	4·8	—	0·7	3·2	3·2	3·9	4·8	—	4	100	17·1
,, separated	9·4	3·5	0·1	5·0	—	0·8	3·3	3·3	0·1	5·0	—	2	100	8·3

*Brands of meat and bone and of feeding meat meal containing no more than 4 per cent of oil, are now available.

,, skimmed, deep set	9·7	3·5	0·4	5·0	—	0·8	3·3	3·3	0·4	5·0	—	2	100	9·1
,, skimmed, shallow set	10·0	3·5	0·7	5·0	—	0·8	3·3	3·3	0·7	5·0	—	2	100	9·8
,, whey	6·6	0·7	0·2	5·0	—	0·7	0·6	0·6	0·2	5·0	—	9	100	6·1
Colostrum (first-drawn)	25·5	17·6	4·2	2·7	—	1·0								
Dried whole milk	95·8	25·5	26·5	37·4	—	6·4								
,, separated milk	89·7	32·8	1·5	47·9	—	7·5								
,, buttermilk	90·0	35·3	7·0	40·0	—	7·7								
,, whey	92·2	12·6	1·4	70·5	—	7·7								
Potato cossettes (meal)	88·0	8·6	0·5	73·4	2·0	3·5	4·7	0·7	—	63·4	1·0	14	100	68·8
,, meal (pigs)	88·0	8·6	0·5	73·4	2·0	3·5	3·4	—	0·15	70·7	1·3	21	—	—
,, flakes (pigs)	90·0	8·2	0·3	75·6	2·1	3·8	6·7	2·1	—	75·6	1·6	12	—	—
,, slices (pigs)	89·0	9·3	0·2	74·0	1·6	3·9	7·0	2·2	—	72·5	0·5	10	—	—
Sugar beet pulp, wet	15·0	1·6	0·1	9·6	3·1	0·6	1·0	1·0	—	8·7	2·8	12	94	11·7
,, ,, ,, dried	90·0	8·9	0·6	59·1	18·3	3·1	5·3	5·0	—	54·0	16·3	13	80·5	60·6
,, ,, ,, molassed	90·0	10·8	0·4	58·2	15·1	5·5	6·3	3·0	—	53·0	13·5	11	80·5	58·3
,, ,, molasses	74·7	3·5	—	66·0	—	5·2	1·2	—	—	59·2	—	—	87	51·6
,, cane molasses	74·2	3·1	—	64·7	—	6·4	1·1	—	—	58·2	—	—	87	50·6
WHEAT FEEDS :														
PURE GRADES														
Finest grade, fine middlings	86·7	17·0	4·2	60·8	2·3	2·4	12·6	11·6	3·7	51·1	—	5	97	69·0
Second grade, coarse middlings or sharps (fine wheat feed)*	86·0	15·9	4·5	55·9	6·0	3·7	11·6	10·1	3·9	45·9	1·4	5	86	56·5
Fourth grade, bran	87·0	15·1	3·8	52·8	9·5	5·8	10·9	8·9	2·6	37·4	2·2	4	77	42·6
Broad bran	87·0	14·7	4·0	52·1	10·3	5·9	11·0	9·0	2·8	36·9	2·2	4	77	42·6
Yeast, dried	93·7	41·5	1·0	41·4	0·2	9·6	35·6	29·4	0·4	34·1	—	1	100	68·3

*Home produced middlings were marketed before the war under the names of Weatings (with a guarantee of not more than 5·75 per cent of fibre) and Superfine Weatings (with a guarantee of not more than 4·5 per cent of fibre).

TABLE 2.—Mineral composition of some common feeding stuffs

—	Total Ash per cent	Lime (CaO) per cent	Phosphoric Acid (P_2O_5) per cent	Potash (K_2O) per cent	Chlorine (Cl_2) per cent
Mangolds	0·9	0·02	0·09	0·45	0·16
Potatoes	1·0	0·03	0·18	0·60	0·04
Swedes	0·7	0·08	0·08	0·30	0·04
Kale, thousand-headed ...	1·7	0·39	0·13	0·52	0·16
Kale, marrow-stem ...	1·9	0·43	0·12	0·55	0·21
Pasture grass (rotational close-grazing)	2·0	0·28	0·16	0·60	0·19
Clover, red, flowering ...	1·6	0·40	0·15	0·50	0·05
Lucerne (early flower) ...	2·4	0·96	0·12	0·43	0·08
Lucerne meal	9·2	2·73	0·78	1·82	0·55
Meadow hay, good ...	6·2	1·00	0·43	1·60	0·37
Red clover hay	7·0	1·60	0·39	2·20	0·24
Seeds hay	6·3	2·00	0·60	1·80	0·30
Oat straw	4·9	0·36	0·18	1·50	0·30
Wheat straw	5·3	0·29	0·13	0·80	0·20
Barley	2·6	0·07	0·84	0·57	0·12
Maize	1·3	0·02	0·82	0·40	0·07
Oats	3·1	0·14	0·81	0·55	0·07
Wheat	1·7	0·05	0·86	0·60	0·08
Beans	3·2	0·18	0·88	1·28	0·03
Peas	2·8	0·10	0·90	1·00	0·04
Bran	5·8	0·20	2·80	1·50	0·09
Middlings (weatings) ...	3·7	0·13	1·50	1·40	0·07
Coconut cake	5·4	0·50	1·50	2·00	?
Cotton cake, undec. ...	5·8	0·30	2·50	1·60	0·05
Groundnut cake, undec. ...	5·7	0·20	1·00	1·10	?
Groundnut cake, dec. ...	5·8	0·20	1·30	1·50	0·03
Linseed cake	5·2	0·51	1·70	1·30	0·09
Palm kernel cake	3·8	0·30	1·10	0·50	0·16
Soya-bean cake	5·4	0·30	2·00	1·80	0·03
Fish meal, white	22·0	10·00	9·00	1·20	1·00
Meat meal, pure	3·8	0·40	0·70	0·10	0·27
Meat meal	19·0	8·00	7·20	0·70	1·20
Meat and bone meal ...	24·0	10·50	9·30	0·80	1·40
Blood meal...	2·7	0·05	0·22	0·31	0·85
Yeast, dried	9·6	0·30	5·50	2·00	0·03
Milk, whole	0·8	0·17	0·20	0·20	0·10
Milk separated	0·8	0·15	0·20	0·20	0·10
Whey	0·7	0·10	0·10	0·15	0·07
Brewers' grains, dried ...	3·9	0·40	1·60	0·20	0·06
Distillers' grains, dried ...	1·8	0·40	0·68	0·20	0·06
Steamed bone flour (dry matter)	88·7	45·80	31·10	?	?

INDEX